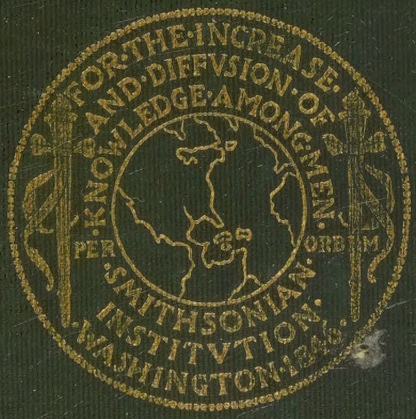
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ANNUAL REPORT
OF THE BOARD OF REGENTS OF

THE SMITHSONIAN INSTITUTION

SHOWING THE OPERATIONS, EXPENDITURES
AND CONDITION OF THE INSTITUTION
FOR THE YEAR ENDING JUNE 30

1908

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LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

ACCOMPANYING

The Annual Report of the Board of Regents of the Institution for the year ending June 30, 1908.

SMITHSONIAN INSTITUTION,
Washington, June 12, 1909.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the Annual Report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1908.

I have the honor to be, very respectfully, your obedient servant,

CHARLES D. WALCOTT,
Secretary.

ANNUAL REPORT OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1908.

SUBJECTS.

1. Annual report of the secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1908, with statistics of exchanges, etc.

2. Report of the executive committee, exhibiting the financial affairs of the Institution, including a statement of the Smithson fund, and receipts and expenditures for the year ending June 30, 1908.

3. Proceedings of the Board of Regents for the sessions of December 3, 1907, and January 22 and February 12, 1908.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1908.

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THE SMITHSONIAN INSTITUTION.

JUNE 30, 1908.

Presiding officer ex officio.—THEODORE ROOSEVELT, President of the United States.
Chancellor.—MELVILLE W. FULLER, Chief Justice of the United States.
Members of the Institution:

THEODORE ROOSEVELT, President of the United States.
CHARLES W. FAIRBANKS, Vice-President of the United States.
MELVILLE W. FULLER, Chief Justice of the United States.
ELIHU ROOT, Secretary of State.
GEORGE B. CORTELYOU, Secretary of the Treasury.
WILLIAM H. TAFT, Secretary of War..
CHARLES J. BONAPARTE, Attorney-General.
GEORGE VON L. MEYER, Postmaster-General.
VICTOR H. METCALF, Secretary of the Navy.
JAMES R. GARFIELD, Secretary of the Interior.
JAMES WILSON, Secretary of Agriculture.
OSCAR S. STRAUS, Secretary of Commerce and Labor.

Regents of the Institution:

MELVILLE W. FULLER, Chief Justice of the United States, Chancellor.
CHARLES W. FAIRBANKS, Vice-President of the United States.
SHELBY M. CULLOM, Member of the Senate.
HENRY CABOT LODGE, Member of the Senate.
A. O. BACON, Member of the Senate.
JOHN DALZELL, Member of the House of Representatives.
JAMES R. MANN, Member of the House of Representatives.
WILLIAM M. HOWARD, Member of the House of Representatives.
JAMES B. ANGELL, citizen of Michigan.
ANDREW D. WHITE, citizen of New York.
JOHN B. HENDERSON, citizen of Washington, D. C.
ALEXANDER GRAHAM BELL, citizen of Washington, D. C.
GEORGE GRAY, citizen of Delaware.
CHARLES F. CHOATE, Jr., citizen of Massachusetts.

Executive Committee.—J. B. HENDERSON, ALEXANDER GRAHAM BELL, JOHN DALZELL.
Secretary of the Institution.—CHARLES D. WALCOTT.
Assistant Secretaries.—RICHARD RATHBUN; CYRUS ADLER.
Chief Clerk.—HARRY W. DORSEY.
Accountant and Disbursing Agent.—W. I. ADAMS.
Editor.—A. HOWARD CLARK.

NATIONAL MUSEUM.

Assistant Secretary in Charge.—Richard Rathbun.
Administrative Assistant.—W. de C. Ravenel.
Head Curators.—F. W. True, G. P. Merrill, Otis T. Mason.
Curators.—Cyrus Adler, Ray S. Bassler, A. Howard Clark, F. V. Coville, W. H. Dall, B. W. Evermann, J. M. Flint, U. S. N. (retired), W. H. Holmes, L. O. Howard, Richard Rathbun, Robert Ridgway, Leonhard Stejneger, Charles D. Walcott.
Associate Curators.—J. N. Rose, David White.
Curator, National Gallery of Art.—W. H. Holmes.
Chief of Correspondence and Documents.—Randolph I. Geare.
Superintendent of Construction and Labor.—J. S. Goldsmith.
Editor.—Marcus Benjamin.
Photographer.—T. W. Smillie.
Registrar.—S. C. Brown.

BUREAU OR AMERICAN ETHNOLOGY.

Chief.—W. H. Holmes.
Ethnologists.—J. Walter Fewkes, J. N. B. Hewitt, F. W. Hodge, James Mooney, Matilda Coxe Stevenson, John R. Swanton, Cyrus Thomas.
Philologist.—Franz Boas.
Illustrator.—De Lancey W. Gill.

INTERNATIONAL EXCHANGES.

Assistant Secretary in Charge.—Cyrus Adler.
Chief Clerk.—F. V. Berry.

NATIONAL ZOOLOGICAL PARK.

Superintendent.—Frank Baker.
Assistant Superintendent.—A. B. Baker.

ASTROPHYSICAL OBSERVATORY.

Director.—C. G. Abbot.
Aid.—F. E. Fowle, Jr.

BUREAU OF INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Assistant Secretary in Charge.—Cyrus Adler.
Chief Assistant.—L. C. Gunnell.

REPORT

OF THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

CHARLES D. WALCOTT,

FOR THE YEAR ENDING JUNE 30, 1908.

To the Board of Regents of the Smithsonian Institution:

GENTLEMEN: I have the honor to submit a report showing the operations of the Institution during the year ending June 30, 1908, including the work placed under its direction by Congress in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, the Astrophysical Observatory, the regional bureau of the International Catalogue of Scientific Literature, and the excavations on the Casa Grande Reservation.

In the body of this report there is given a general account of the affairs of the Institution, while the appendix presents a more detailed statement by those in direct charge of the different branches of the work. Independently of this the operations of the National Museum and the Bureau of American Ethnology are fully treated in separate volumes. The scientific work of the Astrophysical Observatory, covering its researches for five years, is described in Volume II of the Annals of the Observatory, published during the year.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

By act of Congress approved August 10, 1846, the Smithsonian Institution was created an establishment. Its statutory members are "the President, the Vice-President, the Chief Justice, and the heads of the executive departments."

THE BOARD OF REGENTS.

The Board of Regents consists of the Vice-President and the Chief Justice of the United States as ex-officio members, three members of the Senate, three Members of the House of Representatives, and six

citizens, "two of whom shall be residents of the city of Washington, and the other four shall be inhabitants of some State, but no two of them of the same State."

It is with regret that I have to record the resignation of the Hon. Richard Olney on January 20, 1908. Mr. Olney served on the Board of Regents as a citizen of Massachusetts for eight years.

The following appointments and reappointments of Regents were made during the year: By appointment of the Speaker, December 9, 1907, Representatives John Dalzell, James R. Mann, and William M. Howard, to succeed themselves; by appointment of the President of the Senate on January 14, 1908, Senator Augustus O. Bacon to succeed himself; by joint resolution of Congress approved February 24, 1908, the Hon. Charles F. Choate, jr., of Massachusetts, in place of the Hon. Richard Olney, resigned.

The board met on December 3, 1907, January 22, 1908, and February 12, 1908. The proceedings of these meetings will be printed as customary in the annual report of the board to Congress.

ADMINISTRATION.

With the aid rendered by the several experienced and efficient staffs the administrative work of the Institution and the several branches of the government service committed to its care has progressed in a satisfactory manner during the year. The affairs of the Institution have received prompt administrative consideration, and a united effort has been made to carry out vigorously and conscientiously the fundamental purposes of the Institution, "the increase and diffusion of knowledge."

Under the general supervision of the Secretary the extended and complicated operations of the National Museum have been efficiently managed by the assistant secretary in charge of the National Museum, Mr. Richard Rathbun. Dr. Cyrus Adler, assistant secretary in charge of library and exchanges, has also rendered important service in connection with the regional bureau of the International Catalogue of Scientific Literature and in the general business of the Institution. The affairs of the Bureau of American Ethnology have continued in charge of Mr. W. H. Holmes, Mr. C. G. Abbot has advanced the work of the Astrophysical Observatory, and Dr. Frank Baker has superintended the administration of the National Zoological Park.

The Secretary has availed himself of the assistance of the officers in charge of the various branches and conferred freely with them during the year. Certain changes in the routine of business in the Institution proper and in the several branches have been approved upon recommendation of the committee on business methods.

The routine work of the Institution proper and of the several branches of the government service under its direction was examined in detail during the year, including the methods of correspondence, the handling of freight, the purchase and issuance of property and supplies, the distribution of publications, the receipt and disbursement of moneys, and rules and regulations affecting leaves of absence and other matters relating to the personnel. In order that the most modern advances in office methods might be applied to the Institution where necessary, a subcommittee of the committee on business methods was directed to visit the executive departments and local commercial establishments, and the report of this subcommittee was of material assistance in suggesting needed modifications in the transaction of routine business under the Institution. Among the most important improvements in this direction were certain changes in the accessioning of material received by the National Museum for examination and report. The general effect of the recommendations of the committee has been to reduce the amount of work and to facilitate the dispatch of business.

The advisory committee on printing and publication, appointed in pursuance of executive order of January 20, 1906, which committee is composed of representatives from the Institution and its branches, has rendered valuable assistance in scrutinizing manuscripts proposed for publication and blank forms used in the work of the Institution and its branches.

Appointments to the staffs of the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, and the regional bureau of the International Catalogue of Scientific Literature have been made from time to time as vacancies occurred, in accordance with the civil-service rules and requirements; these establishments, with the exception of the last named, having been placed under the operation of the civil-service law on June 30, 1896, the International Catalogue having later been subjected to the jurisdiction of the commission. No important changes have been made in the routine affecting appointments, except that by executive orders the rules were modified to permit transfers of persons serving for a period of six months ending within one year from the date of proposed transfer, and the requirements of examination were allowed to be waived in the discretion of the Civil Service Commission. The privilege of making emergency appointments, pending the permanent appointment of eligibles through certification, was discontinued, likewise by executive order, and all temporary appointments are required now to be approved in advance by the commission. Such appointments are no longer limited arbitrarily to six months, but may, under certain circumstances, be extended beyond that term. Recommendations

of appointing officers affecting the method of appointment to positions in the classified service are, by executive order of February 20, 1908, required to be forwarded, with a full statement of the reasons therefor, through the Civil Service Commission, to the President.

The current business of the Institution has been conducted in a prompt and effective manner, and it is gratifying to note that no arrearages in the work of the government branches under its direction were necessary to be reported in the quarterly statements to the President and in the annual statement which, in accordance with law, accompanied the estimates transmitted to Congress.

FINANCES.

The permanent fund of the Institution and the sources from which it was derived are as follows:

Deposited in the Treasury of the United States.

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposit from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposit from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins		7,918.69
Total amount of fund in the United States Treasury		944,918.69

Held at the Smithsonian Institution.

Registered and guaranteed bonds of the West Shore Railroad Company (par value), part of legacy of Thomas G. Hodgkins	42,000.00
Total permanent fund	986,918.69

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum, under the provisions of the act organizing the Institution and an act of Congress approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum.

The income of the Institution during the year, amounting to $63,372.96, was derived as follows: Interest on the permanent fund, $58,262.52; proceeds from claims in litigation, $300, and from miscellaneous sources, $4,810.44; all of which was deposited in the Treasury of the United States to the credit of the current account of the Institution.

With the balance of $24,592.01 on July 1, 1907, the total resources for the fiscal year amounted to $87,964.97. The disbursements, which are given in detail in the annual report of the executive committee, amounted to $69,198.56, leaving a balance of $18,766.41 on deposit June 30, 1908, in the United States Treasury.

The Institution was charged by Congress with the disbursement of the following appropriations for the year ending June 30, 1908:

International Exchanges	$32,000
American Ethnology	40,000
Astrophysical Observatory	13,000
National Museum:	
Furniture and fixtures	20,000
Heating and lighting	18,000
Preservation of collections	190,000
Books	2,000
Postage	500
Rent of workshops	4,580
Building repairs	15,000
National Zoological Park	110,000
International Catalogue of Scientific Literature	5,000
Protection and excavation, ruin of Casa Grande, Arizona	3,000
New building for National Museum	1,250,000
Total	1,703,080

Estimates.—The estimates forwarded to Congress in behalf of the Government branches of the Institution and the appropriations based thereon for the fiscal year ending June 30, 1909, are as follows:

	Estimates.	Appropriations.
International Exchanges	$32,000	$32,000
American Ethnology	52,000	42,000
Reimbursement of Bell & Co.	525	.....
Astrophysical Observatory	20,000	13,000
National Museum:		
Furniture and fixtures	[a]200,000	50,000
Heating and lighting	25,000	22,000
Preservation of collections	190,000	190,000
Books	2,000	2,000
Postage	500	500
Rent of workshops	4,580	4,580
Building repairs	15,000	15,000
National gallery of Art	60,000	.....
National Zoological Park	110,000	95,000
Readjustment of boundaries	40,000	.....
International Catalogue of Scientific Literature	5,000	5,000
Total	756,605	471,080

[a] Owing to delay in completion of the new National Museum building the request was made before the Appropriations Committee that $50,000 be appropriated under this item, which was done.

One of the important questions that comes up for consideration annually is that of submitting estimates to the Congress for the support of the several branches placed by the Congress under the administrative charges of the Smithsonian Institution. As the executive officer of the Institution it is my duty to give careful consideration to the administration of the federal branches under its charge and to ascertain as far as possible the needs of each branch, and to see that the conclusions are clearly formulated in the estimates and later presented orally or in printing as the committees in the Congress may desire.

In considering estimates there is necessarily a decided difference in the point of view of the administrative officers in charge of the several branches of the Institution and the members of the congressional appropriation committees. The former see clearly what in their judgment is needed to make the particular work or department in their charge effective and a credit to the American people who own and sustain it. The members of the committee have a general idea of the character of the work being done and its relative importance in comparison with similar work elsewhere, and time is taken for hearings and consideration of individual objects. In deciding on the amount to be appropriated the committee has also in mind the present and prospective condition of the Treasury, the total amount that in their judgment should be appropriated, and how much can be safely assigned to each object to be appropriated for in the act under consideration.

For the fiscal year ending June 30, 1909, the estimates submitted exceeded the appropriations by $285,525. Before the time of the hearing by the subcommittee on appropriations it became evident that the new National Museum building would not be completed in time to make use of the estimated $200,000 for furniture and fixtures, so at the hearing the committee was requested to approve of $50,000, which was done. The items of $40,000 for the readjustment of the boundaries of the National Zoological Park and $60,000 for alterations in the Smithsonian building to provide for the exhibition of the art collections of the Government were omitted by the committee along with some minor increases in the estimates.

In making up the estimates for the fiscal year 1910 the Secretary had to consider, among other matters, the following:

1. The estimates submitted by the officers in charge of the several branches.

2. The reasons submitted for asking an increase in appropriations.

3. The rejection by the Congress of most of the increased estimates for the fiscal year 1909.

4. His duty as an administrative officer to submit to the Congress such estimates as in his judgment would be needed to properly pro-

vide for carrying on the work of the federal branches of the Institution.

Not knowing the conditions or reasons for the rejection of certain estimates for 1909, and feeling that the committees and the Congress had approved of the general plan of operation of the several federal branches of the Institution, I have prepared estimates for the fiscal year 1910 on the basis of securing effectiveness in administration; creditable results both in exhibition, research, and publication; and a natural development so as to compare favorably in the final result with national institutions of the same type in other countries. For instance, I have the feeling that if our Government undertakes to establish and maintain a national zoological park at the capital city it should not rank, as it does now, fifth or sixth among parks of the same type elsewhere. A carefully considered plan has been formulated for the development of the Zoological Park, and the estimates have been made in accordance with it. The same has been done for the National Museum and the Bureau of American Ethnology.

EXPLORATIONS AND RESEARCHES.

The resources of the Smithsonian Institution are at present too limited to permit of large grants for extensive explorations or investigations, but as far as the income allows aid is given in various lines of research work and it is sometimes found possible to engage in expeditions likely to accomplish important results. If funds could be obtained to be administered under the Institution, the scientific work of the Government might often be supplemented by original researches of a character that would hardly be undertaken by the Government, and which would be of great service to humanity and to science.

Through the National Museum, the Bureau of American Ethnology, and the Astrophysical Observatory the Institution has been enabled to carry on various biological, ethnological, and astrophysical researches, which will be found fully described elsewhere in this report.

STUDIES IN CAMBRIAN GEOLOGY AND PALEONTOLOGY.

In my last report reference was made to studies of the older sedimentary rocks of the North American Continent which I have been carrying on for the past twenty years. This work was continued in the Canadian Rockies during the field season of 1907. Early in July a camp outfit was secured at Field, British Columbia, and work begun on Mount Stephen. Subsequently sections were studied and measured at Castle Mountain, west of Banff, Alberta; at Lake Louise, south of Laggan, Alberta; and on Mount Bosworth, on the Continental Divide near Hector, British Columbia. Upward of 20,000

feet of strata were carefully examined and measured, and collections of fossils and rocks made from many localities. It was found that the Cambrian section included over 12,000 feet of sandstones, shales, and limestones, and that the three great divisions of the Cambrian—the Lower, Middle, and Upper—were represented in the Bow River series and the Castle Mountain group. Characteristic fossils were found in each division. At the close of the fiscal year papers were in type[a] describing the sections measured and giving lists of the faunas obtained at the various horizons. The field season of 1908 will be spent in Montana, British Columbia, and Alberta in an attempt to correlate the pre-Cambrian formations of Montana studied in 1905,[b] with those described by Willis and Daly in the vicinity of the Forty-ninth parallel.

AERIAL NAVIGATION.

Within the past year there has been a renewed interest in experiments in aerial navigation, to which this Institution, through my predecessor, Mr. Langley, made notable contributions. Toward the end of the year the demand for literature on the subject so entirely exhausted the supply of papers on hand, that a special edition of some of Mr. Langley's more popular memoirs was issued. It is gratifying to me to be able to say that his pioneer work in heavier-than-air machines, resulting as it did in the actual demonstration of the possibility of mechanical flight, has now received universal recognition.

Besides numerous popular papers, Mr. Langley wrote two technical works relating to the general subject of aerodromics, which form parts of an incomplete volume of the Smithsonian Contributions to Knowledge. The record of his experiments from 1893 to 1905 was kept by him partly in manuscript form and largely in the shape of voluminous notes and wastebooks. These have been turned over to his principal assistant in this work, Mr. Charles M. Manly, who has been for some time engaged in preparing them for publication and adding such necessary information, especially on the engineering side, as comes within the immediate purview of Mr. Manly's work. It is a source of regret that the memoir has not yet been completed for publication, but I hope that during this year it will be possible for the Institution to issue the volume, thus bringing to a conclusion a record of Mr. Langley's original and epoch-making contributions

[a] Canadian Alpine Journal, Vol. I, No. 2, 1908, pp. 232–248: Mount Stephen rocks and fossils.

Smithsonian Miscellaneous Collections, Vol. LIII, Cambrian Geology and Paleontology, No. 5, 1908, pp. 167–230: Cambrian sections of the Cordilleran area.

[b] Bull. Geol. Soc. America, vol. 17, 1906, pp. 1–28: Algonkian formations of northwestern Montana.

to a science and an art which bid fair to engage the attention of mankind for many years to come.

METEOR CRATER OF CANYON DIABLO, ARIZONA.

An investigation of the remarkable crater-like depression at Coon Butte, near Canyon Diablo, Arizona, made in 1907 by Dr. G. P. Merrill, head curator of geology in the National Museum, aided by a grant from the Smithsonian Institution, was briefly mentioned in my last year's report and a full account appeared in the Smithsonian Miscellaneous Collections (quarterly issue) under date of January 27, 1908. The "crater" is some three-fourths of a mile in diameter and 500 feet in depth in a region of undisturbed sedimentary rocks and remote from volcanoes. The object of the study was to determine, if possible, whether the crater was caused by volcanic action, as assumed by some investigators, or due to the impact of a mass of meteoric iron as asserted by others.

From the available evidence Doctor Merrill concluded that the crater could not have been formed by volcanic action, all the observed phenomena being of a superficial nature. Some 300 feet of overlying limestone and 500 feet of sandstone have been shattered as by some powerful blow, and the quartz particles in the sandstone in part fused, indicating a very high degree of heat. The deeper-lying sandstone, however, is entirely unchanged. These facts absolutely preclude the formation of the crater by any deep-seated agency, and forces the conclusion that it resulted from the impact of a stellar body.

No record has been found of a meteoric fall comparable with this, the largest known meteorites, such as that from Cape York, Greenland, and the enormous irons from Oregon, having fallen under such conditions as to scarcely bury themselves. The nearest approach to the Canyon Diablo occurrence was that at Knyahinya, Hungary, where a 660-pound stone penetrated the ground to a depth of 11 feet. No meteoric mass of sufficient size to have made this enormous crater has been brought to light, but it is thought there still remains the possibility of its having become dissipated through the heat developed by its impact while traveling at a speed of many miles a second.

In his report Doctor Merrill goes very thoroughly into details. He has secured many specimens of the meteoric irons and their associations from the locality, which are deposited in the National Museum. The specimens include a hitherto unrecognized type of meteoric iron and a peculiar form of metamorphism in the siliceous sandstone of the region.

Mining operations carried on in the crater afforded special opportunity for this research. These operations were discontinued during the winter, but their resumption in May, 1908, presented a second

opportunity for the observation of the unique phenomena at the crater, and Doctor Merrill was authorized to proceed again to Arizona to be present during this second, and probably final, series of drillings. The greatest depth reached during his stay at the crater was 842 feet, and the results of the examination of the ejectamenta thus secured confirmed the former conclusion. Several boxes of specimens bearing on the subject were forwarded to the Institution, where they will be held for future reference and study.

ALASKAN EXPEDITION.

In my last report mention was made of an expedition to be made to the Yukon country in Alaska for the collection of the remains of large extinct vertebrates, particularly mammals. A Smithsonian expedition had been made to this region in the summer of 1904 by Mr. Maddren, the results of which were published by the Institution in 1905. The present expedition of 1907 was in charge of Mr. C. W. Gilmore of the National Museum. The results of the explorations have been published in the Smithsonian Miscellaneous Collections.

Mr. Gilmore was not successful in finding what was most desired, a fairly complete skeleton of a mammoth, but the expedition was by no means barren of results. He found that scattered remains of Pleistocene animals occur throughout the unglaciated region of Alaska and adjacent Canadian territory in the black muck accumulated in gulches and the valleys of the smaller streams, in the fine elevated clays of the Yukon silts, and Kowak clays, and in the more recent fluvial and alluvial deposits. Some of the specimens are so well preserved that they could not have traveled far from the original place of interment, while many bones are broken, abraded, and waterworn. Mr. Gilmore gives a list of the various genera and species of extinct vertebrates thus far reported from Alaska, followed by a brief review with a number of illustrations. He believes that when more perfect material is available it will be found, probably in all instances, to be quite distinct from the living forms. The skull of an *Ovibos* was found sufficiently complete to warrant its separation from the living form *O. moschatus*, to which nearly all musk-ox material from this region had previously been referred.

GEOLOGY OF THE ALPS.

The investigation by Mr. Bailey Willis of the current theories of Alpine structure, under the grant approved in 1907, was successful in offering opportunities for consultation with leading European geologists, among whom were Rothpletz, Suess, Lugeon, Margerie, and Saccord. In cooperation with several distinguished students of the great problems of the Alps, Mr. Willis made detailed studies of

critical districts, and was thus enabled to compare opposing theories by object lessons on the ground. Mr. Willis's full report is expected early in 1909.

ABSOLUTE MEASUREMENT OF SOUND.

Dr. A. G. Webster announces the approaching completion of his research on the measurement of sound which has been in progress for two years past. The investigation comprises an exhaustive treatment of the theory of the production of sound, with a description of a standard source, the transmission of sound through the air as modified by the effect of the ground, and its measurement by a receiving instrument. A description of experiments confirming the theory of Doctor Webster will be included in his finished report, with several practical applications, such as the examination of the sounds of speech, the diagnosis of deafness, the improvement of fog signals, and the testing of materials for the insulation of sound.

RECALCULATION OF ATOMIC WEIGHTS.

In February, 1908, Prof. F. W. Clarke, chairman of the International Commission on Atomic Weights, was authorized to begin the preparation of a third edition of his work on that subject, with the aid of a grant from the Smithsonian Institution. The second edition of Professor Clarke's Atomic Weights was published in 1897, since which time the data on this subject have so largely increased as to render a new edition desirable. Some time will necessarily elapse before the completion of the work.

PROPERTIES OF MATTER AT TEMPERATURE OF LIQUID AIR.

In October, 1907, a Smithsonian grant was approved on behalf of Prof. E. L. Nichols, of Cornell University, for the continuation of his experiments on the properties of matter at the temperature of liquid air. Reports of the progress of this research are to be made from time to time in the recognized journals of physics and, at the completion of the research, a memoir describing the investigation will be submitted to the Smithsonian Institution for consideration as to publication. It is believed that the prompt announcement of results in the way mentioned will be an immediate advantage to students, and that their publication as a whole by the Institution will also prove of great service.

BOTANICAL RESEARCHES IN CALIFORNIA.

A moderate grant has been made to Miss Alice Eastwood from the Smithsonian fund for the critical field study and collection of the species and genera of the plants secured at the type locality, Santa Bar-

bara, Cal., by Thomas Nuttall, and published by him in 1838 to 1843. Some of these species are now well known, but others have never been collected and arranged since they were found by Nuttall, and several are known to be misunderstood. The collection Miss Eastwood is now making will be valuable for the series in the herbarium of the National Museum.

DEEP-WELL TEMPERATURES.

A moderate Smithsonian grant was approved on behalf of Dr. William Hallock, of Columbia University, to assist in the investigation of temperatures in a deep well near Oakland, Md., for purposes of geological research.

INVESTIGATIONS UNDER THE HODGKINS FUND.

I have given a good deal of consideration to the use of that portion of the Hodgkins fund devoted to the increase and diffusion of more exact knowledge of the atmospheric air in relation to the welfare of man. While much valuable work has been done under this fund, it seems to me that it would be more in consonance with the ideas of the founder, if at least a portion of it might be employed in some way to aid in the knowledge of the prevention of disease and its cure. I have been in correspondence with several specialists and hope to be able to initiate some useful investigations along these lines.

HODGKINS FUND PRIZE FOR ESSAY ON TUBERCULOSIS.

Under date of February 3, 1908, the Institution issued a circular announcing a prize of $1,500 for the best treatise "On the relation of atmospheric air to tuberculosis" that should be offered at the international congress on tuberculosis, to be held in Washington from September 21 to October 12, 1908. The circular reads as follows:

SMITHSONIAN INSTITUTION—HODGKINS-FUND PRIZE.

In October, 1891, Thomas George Hodgkins, esq., of Setauket, N. Y., made a donation to the Smithsonian Institution the income from a part of which was to be devoted to "the increase and diffusion of more exact knowledge in regard to the nature and properties of atmospheric air in connection with the welfare of man." In furtherance of the donor's wishes, the Smithsonian Institution has from time to time offered prizes, awarded medals, made grants for investigations, and issued publications.

In connection with the approaching international congress on tuberculosis, which will be held in Washington, September 21 to October 12, 1908, a prize of $1,500 is offered for the best treatise "On the relation of atmospheric air to tuberculosis." Memoirs having relation to the cause, spread, prevention, or cure of tuberculosis are included within the general terms of the subject.

Any memoir read before the international congress on tuberculosis, or sent to the Smithsonian Institution or to the secretary-general of the congress before its close, namely, October 12, 1908, will be considered in the competition.

The memoirs may be written in English, French, German, Spanish, or Italian. They should be submitted either in manuscript or typewritten copy, or if in type, printed as manuscript. If written in German they should be in Latin script. They will be examined and the prize awarded by a committee appointed by the Secretary of the Smithsonian Institution in conjunction with the officers of the international congress on tuberculosis.

Such memoirs must not have been published prior to the congress. The Smithsonian Institution reserves the right to publish the treatise to which the prize is awarded.

No condition as to the length of the treatises is established, it being expected that the practical results of important investigations will be set forth as convincingly and tersely as the subject will permit.

The right is reserved to award no prize if in the judgment of the committee no contribution is offered of sufficient merit to warrant such action.

Memoirs designed for consideration should be addressed to either "The Smithsonian Institution, Washington, D. C., U. S. A.," or to "Dr. John S. Fulton, secretary-general of the international congress on tuberculosis, 714 Colorado Building, Washington, D. C., U. S. A." Further information, if desired by persons intending to become competitors, will be furnished on application.

CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

As a committee to award this prize the following gentlemen have consented to serve: Dr. William H. Welch, of Johns Hopkins, chairman; Dr. John S. Fulton, secretary-general of the congress; Dr. Simon Flexner, director, Rockefeller Institute for Medical Research, New York; Dr. George M. Sternberg, Surgeon-General, U. S. Army, retired; Dr. Hermann Biggs, New York department of health; Dr. George Dock, of the University of Michigan; and Dr. William M. Davis, of Harvard.

FLOW OF AIR AT HIGH PRESSURE THROUGH A NOZZLE.

The inquiry to determine the cooling effect of the nozzle expansion of air for large pressure differences, which has been conducted by Prof. W. P. Bradley, of Wesleyan University, with the aid of a grant from the Hodgkins fund of the Institution, is announced as nearing completion. The investigation was intended specifically to determine whether the cooling process is due to the Joule-Thomson effect or to the performance of external work by the expanding air in pushing back the atmosphere from before the nozzle. The results of the inquiry make it clear that pressure is an important factor and that the cooling effect increases very rapidly indeed as the initial temperature falls. Professor Bradley is now engaged in an exact mathematical discussion of this research.

As to the apparatus employed, an interchanger of the Hampton type was so constructed, in vertical sections, that the amount of interchanger surface in actual use could be varied at will, from nothing to more than enough to induce liquefaction. In this manner it

was possible to maintain the initial temperature constant, within one-third of a degree, at any desired point between +20° and −120°, and the final temperature similarly constant between +20° and the temperature of liquefaction. The temperatures were measured by resistance thermometers placed close to the valves in the high and low pressure circuits. The pressures employed range from 500 pounds to 3,000 pounds. The expansion was exclusively to one atmosphere.

The inquiry is of interest as related to the functioning of air liquefiers in which the air is throttled by a valve and expands without performing external work, in the usual sense of that expression.

STUDY OF THE UPPER ATMOSPHERE.

A further grant from the Hodgkins fund was made to Prof. A. Lawrence Rotch, director of the Blue Hill Meteorological Observatory, to aid in the completion of his experiments with ballons-sondes at St. Louis. This was accomplished in October and November, 1907, under the direction of Mr. S. P. Fergusson.

The object of these latest ascensions, 21 in number, was to supply data for the high atmosphere during the autumn, a season when there are few observations, and also to establish a comparison with the results obtained simultaneously in Europe on the international term days in October and November. Professor Rotch reports that all but two of the instruments used in these ascensions were recovered, and an examination of the record sheets indicates generally the presence, at an altitude exceeding 8 miles, of the isothermal, or relatively warm stratum, which was found somewhat lower in summer. For example, on October 8 the minimum temperature of 90° F. below zero was found at a height of 47,600 feet, whereas at the extreme altitude reached—namely, 54,100 feet—the temperature had risen to 72° F. below zero. Similarly, on October 10 the lowest temperature of 80° F. below zero occurred at 39,700 feet, while 69° F. below zero was recorded at 49,200 feet, the limit of this ascension, showing that the temperature inversion had come down about 8,000 feet in two days.

The prevailing drift of the balloons during the autumn of 1907 was from the northwest, while in previous years they traveled more from the west. A description of the methods employed in launching 77 ballons-sondes from St. Louis and a discussion of the results obtained will soon appear in the Annals of the Astronomical Observatory of Harvard College.

AIR SACS OF THE PIGEON.

For several years there have been in progress under the general direction of Prof. von Lendenfeld, of the University of Prague, aided by grants from the Hodgkins fund, various investigations bearing upon animal flight. The results of one of these investigations, on

"The air sacs of the pigeon," by Bruno Müller, was published during the past year in the Smithsonian Miscellaneous Collections. The author summarizes the conclusions of his studies as follows:

I do not consider the air sacs, including the air cavities of bones, as organs having a positive and special function, but rather as a system of empty interspaces. Their value lies in their emptiness—that is, in their containing nothing that offers resistance or has an appreciable weight.

Flying is the highest form of locomotion, and as such only possible to a body of high mechanical efficiency. Our most effective machines are by no means compact and solid, but composed of parts as strong as possible in themselves and arranged in the most appropriate manner. The interspaces between the parts are left empty and taken up by air.

The Sauropsida, at the time they obtained the power of flight, became adapted to its mechanical requirements, and thereby similar to the efficient machines mentioned above; they divested themselves of all superfluous material, filling the body spaces thus obtained with air sacs. While the body wall, adapting itself to the mechanical requirement, became a compact, hollow cylinder serving as a support for the organs of movement, the mobility of the parts was assured by surrounding them with air sacs.

The lengthening of the neck, produced by quite a different adaptation, made necessary an increase in the quantity of air moved during respiration. This demand was met by air currents generated through a rhythmical change in the volume of the air sacs. The connection of the air sacs with the lungs is a consequence of their phylogenetic development, which is repeated in their embryological development, and has no physiological significance other than that the air sacs assist in renewing the air in the trachea.

MECHANICS OF THE EARTH'S ATMOSPHERE.

Prof. Cleveland Abbe, who has received a Hodgkins grant for the preparation of a second volume of translations of important foreign memoirs on the mechanics of the earth's atmosphere, has about completed this work. The former collection of translations on this subject by Professor Abbe, published in 1891 as volume 34 of the Smithsonian Miscellaneous Collections, has been widely used and recognized to be of important service to those engaged in the study of modern dynamic meteorology.

NAPLES ZOOLOGICAL STATION.

For the past fifteen years the Smithsonian Institution has supported a table at the Naples Zoological Station and offered its facilities for study to biologists recommended by an advisory committee of eminent specialists. During the past year I have been aided by the prompt and helpful action of this committee, whose membership continues the same as heretofore.

The occupation of the Smithsonian table was approved on behalf of Mr. J. F. Lewis, of Johns Hopkins University, for the month of March, 1908. His actual stay, however, exceeded that period by some

two weeks. Mr. Lewis has submitted an outline of his work, in which he says:

My work at Naples was in continuation of lines of investigation already under way. It consisted mainly in the collection and preservation of material for a cytological study of Rhodophyceæ, with a view to gathering evidence as to the extent of the remarkable alternation of generations in this group of plants. Material was collected and carefully preserved of *Dudresnaya coccinea*, various species of *Callithamnion*, and other forms. My comparatively short stay at Naples precluded my making at the time the careful cytological investigation which must precede the drawing of any conclusions as to the presence or absence of alternation of generations in the forms studied. This investigation is now in progress and should lead to definite results of some theoretical value. During my stay at Naples I also investigated the periodicity in the production in the sexual cells of *Dictyola dichotoma*. This subject has been investigated by J. Lloyd Williams on the coasts of England and Wales, and by W. D. Hoyt on our own Atlantic coast. In both cases it has been found that the production of sexual cells bears a very definite relation to the changes of the tides. It was thought, therefore, to be of special interest to find how *Dictyola* behaves in seas where the tides are very slight and where tidal influences are almost negligible. The results of this investigation are practically ready for publication.

Prof. F. M. Andrews, of the University of Indiana, received the appointment to the table for the months of April and May, 1908, going there from a period of research work with Professor Pfeffer, at the University of Leipzig. At Naples Professor Andrews was engaged on a problem in plant physiology, a summary of the results of which will receive mention when submitted to the Institution.

Dr. C. A. Kofoid, associate professor of histology and embryology in the University of California, and assistant director of the San Diego Marine Biological Station, will occupy the table for three months from January 1, 1909. While at Naples Doctor Kofoid proposes a research on sexual reproduction among Dinoflagellata, as yet unknown in marine forms. He will also study the Gymnodiniidæ, which can be done only in the living condition, as they resist all attempts at fixing. In addition to these investigations, he proposes some experimental work on autotomy in Ceratium, with reference to temperature and vertical distribution in the sea.

The application of Dr. M. F. Guyer, professor of zoology in the University of Cincinnati, has been approved for April, May, and June, 1909. Doctor Guyer has contributed to various scientific publications articles already well known, describing his investigations, and on the close of his term at Naples is expected to send a brief outline of his work there to the Institution.

To avoid the complications which may arise from the overlapping of the dates of appointees to the table, a longer time is at present allowed between the approval of an appointment and the time of occupation than was at first found practicable. It is hoped that this plan will allow a wider choice in the selection of dates, and tend to

make the table available for the use of a greater number of investigators than could otherwise be accommodated.

In the past fifteen years only one instance has occurred in which an investigator has applied for the Smithsonian seat after having asked the privilege of occupying another table for the same period. The confusion which necessarily results from such action will be readily appreciated. To meet the wish of the director, a double appointment on behalf of the Institution, for even a limited time, is not approved without inquiry as to the convenience of the station in the matter. It should be again noted, however, that the director of the station is always most courteously ready to arrange for the accommodation of more than one appointee when, on being notified in advance, he finds such action practicable.

PUBLICATIONS.

Three series of publications are maintained by the Institution proper, (1) the Smithsonian Contributions to Knowledge, (2) the Smithsonian Miscellaneous Collections, and (3) the Annual Reports to Congress; while under its auspices there are issued Annual Reports, Proceedings, and Bulletins of the National Museum, Annual Reports and Bulletins of the Bureau of American Ethnology, and Annals of the Astrophysical Observatory.

The Smithsonian Contributions to Knowledge are restricted to positive additions to human knowledge resting on original research, unverified speculations being excluded therefrom. The Smithsonian Miscellaneous Collections contain reports showing progress in particular branches of science, lists and synopses of species of the organic and inorganic world, accounts of explorations, and aids to bibliographical investigations.

Three memoirs of the Smithsonian Contributions to Knowledge, which were in press at the close of the last fiscal year, have been completed and distributed. One of these is a memoir of 147 pages and 42 plates by Dr. William Hittell Sherzer, giving the results of his studies of the glaciers of the Canadian Rockies and Selkirks. Doctor Sherzer explains the physiographic changes of the past and those now in progress in these regions, and gives the results of his observations on the structure of glacial ice and movements of the glaciers. The second completed memoir of 79 pages and 10 plates is by Prof. E. A. Andrews, on "The Young of the Crayfish Astacus and Cambarus," and the third memoir of 231 pages and 13 plates is by Prof. Hubert Lyman Clark, on "The Apodous Holothurians, a Monograph of the Synaptidæ and Molopodiidæ," including a report on the representatives of these families in the National Museum collections.

To meet the continued demand for the memoir by the late Secretary Langley on "The Internal Work of the Wind," first issued in 1893, a new edition has been put to press, adding to the original a translation of a "Solution of a Special Case of the General Problem," by Réné de Saussure, which appeared in the French edition of the work in 1893.

Forty papers were published in the Smithsonian Miscellaneous Collections during the year, 32 of them aggregating 500 pages, in the quarterly issue of that series, and 8 papers, 647 pages, in the regular series. These papers cover a wide range of topics, as enumerated by the editor in his report on publications.

There was published in the Smithsonian Miscellaneous Collections a paper on "The Development of the American Alligator" describing the results of investigations by Prof. Albert M. Reese, of Syracuse University, who had been aided in his work by a grant from the Smithsonian Institution. A brief paper recording the observations by Professor Reese on the breeding habits of the Florida alligator was published in the Quarterly Issue of the Miscellaneous Collections under date of May 4, 1907.

A volume of the Smithsonian Miscellaneous Collections will be devoted to a series of papers by the secretary on Cambrian geology and paleontology. Two papers of this series, No. 1, "Nomenclature of Some Cordilleran Formations," and No. 2, "Cambrian Trilobites," were published before the close of the fiscal year. Three additional papers were in proof form at the close of the year, namely, No. 3, "Cambrian Brachiopoda: Descriptions of New Genera and Species;" No. 4, "Classification and Terminology of the Cambrian Brachiopoda;" and No. 5, "Cambrian Sections of the Cordilleran Area."

The series of Smithsonian Tables continues to be in demand. A revised edition of the Meteorological Tables has been published, and a revised edition of the Physical Tables was in preparation for the printer when the year closed. To this series of Meteorological, Physical, and Geographical Tables, there will be added a fourth volume, "Smithsonian Mathematical Tables: Hyperbolic Functions," prepared by Dr. George F. Becker and Mr. C. E. Van Orstrand. This volume of between 300 and 400 pages is now in press. In the introduction to the work the authors say:

> The hyperbolic functions are named the hyperbolic sine, cosine, tangent, cotangent, secant, and cosecant from their close analogy to the circular functions, the tangent being the ratio of the hyperbolic sine to the cosine and the other three functions being the reciprocals of these, as in circular trigonometry. They are usually denoted by adding *h* to the symbols of the circular functions, as cosh *u* for the hyperbolic cosine of *u*, sinh *u* for the hyperbolic sine of *u*, etc.
>
> The first and most important application of the functions now known as hyperbolic was made by Gerhard Mercator (Kremer) when he issued his map

on "Mercator's projection," in 1559, or, as some say, in 1550, while Bowditch gives the date as 1566. To this day substantially all of the deep-sea navigation of the world is carried on by the help of this projection, which has been modified only to the extent of correcting the meridional parts for the ellipticity of the meridian.

The Annual Report of the Board of Regents to Congress, published under an allotment granted by Congress, continues to be the principal medium through which the Institution disseminates scientific information to the world at large. For nearly sixty years this report has included an appendix recording progress in different branches of knowledge, the articles being compiled largely from journals in foreign languages and the transactions of scientific and learned societies throughout the world, comprising material otherwise not readily accessible. It is impossible to meet the popular demand for this publication, even from the considerable edition authorized by Congress, so that the distribution of the 7,000 copies at the disposal of the Institution must therefore be largely limited to libraries and institutions where the public may refer to them.

The 1907 annual report was in type, but presswork could not be completed before the close of the fiscal year. This volume includes 29 articles on the customary wide range of topics.

The publications of the National Museum during the year included the annual report and a large number of papers of the bulletins and proceedings, mentioned by the assistant secretary in the appendix of the present report.

The twenty-fifth annual report and three bulletins of the Bureau of American Ethnology, as also a special publication on "Indian Missions" were issued during the year, and a number of works were in press when the year closed, including a bulletin on "Unwritten Literature of Hawaii," and Part I of "Handbook of American Indian Languages." Part II of the "Handbook of American Indians" is still in press, the critical character of the contents of this work rendering rapid progress undesirable.

The first volume of the Annals of the Astrophysical Observatory was published in 1902, and the second volume, recording the results of investigations from 1900 to 1906, has now been published. The research described in this volume is a continuation of observations on the relations of the sun to climate and life upon the earth, a line of investigation inaugurated by the late Secretary Langley.

In compliance with the acts of incorporation of the American Historical Association and of the National Society of the Daughters of the American Revolution, the annual reports of those bodies were submitted to the secretary of the Smithsonian and transmitted to Congress.

The Department of State has transmitted a number of reports by American consuls bearing on the Indians of Peru, Education in For-

mosa, and other topics, some of which have been printed in the Smithsonian Miscellaneous Collections.

The monograph on Landmarks in Botanical History, referred to in previous reports as in course of preparation by Dr. Edward L. Greene, is progressing satisfactorily and will be published by the Institution when completed.

A bibliography of tin is in preparation by Mr. F. L. Hess, with the aid of a Smithsonian grant; and under the Hodgkins fund a bibliography of aeronautics is being compiled by Mr. Paul Brockett.

In accordance with the act of Congress approved March 30, 1906, providing that the cost of printing and binding for the executive departments and government bureaus shall be charged to specific allotments for the departments and bureaus, and the further provision in the sundry civil act of June 30, 1906, that no appropriations except those specifically for printing and binding shall be used for such purpose, special allotments have been made to the Institution and its branches for the year ending June 30, 1909, as follows:

For the Smithsonian Institution for printing and binding annual reports of the Board of Regents, with general appendixes	$10,000.00
For the annual reports of the National Museum, with general appendixes, and for printing labels and blanks, and for the bulletins and proceedings of the National Museum, the editions of which shall not exceed 4,000 copies, and binding, in half turkey or material not more expensive, scientific books and pamphlets presented to and acquired by the National Museum library	34,000.00
For the annual reports and bulletins of the Bureau of American Ethnology, and for miscellaneous printing and binding for the bureau	21,000.00
For miscellaneous printing and binding:	
International Exchanges	200.00
International Catalogue of Scientific Literature	100.00
National Zoological Park	200.00
Astrophysical Observatory	100.00
For the annual report of the American Historical Association	7,000.00
Total	72,600.00

The allotments to the Institution and its branches under the head of public printing and binding during the past fiscal year were as far as practicable expended prior to June 30. The protracted session of Congress, however, prevented the completion of considerable work in hand during the latter part of the fiscal year, making it impossible to entirely use some of the allotments.

Continuing the policy established last year, an editorial assistant has been engaged in abstracting such publications of the Institution and its branches as could be put in popular language for the use of newspapers throughout the country. A number of more general articles on the work of the Institution have also been distributed to the

press. This has resulted in reaching millions of readers who would not have ready access to the scientific information in the publications of the Institution.

ADVISORY COMMITTEE ON PRINTING AND PUBLICATION.

In order that the practice of the Institution in the supervision of its publication and those of its branches might correspond with that of the executive departments, as prescribed by the President's order of January 24, 1906, the Smithsonian advisory committee on printing and publication, appointed February 7, 1906, held 26 meetings during the year and reported on 137 manuscripts and numerous blank forms. The committee also considered various questions pertaining to printing and binding.

The committee consists of the following members: Dr. Cyrus Adler, assistant secretary, chairman; Dr. F. W. True, head curator of biology, U. S. National Museum; Mr. F. W. Hodge, ethnologist, the Bureau of American Ethnology; Dr. Frank Baker, superintendent, National Zoological Park; Mr. C. G. Abbot, director of the Astrophysical Observatory; Mr. W. I. Adams, of the International Exchanges; Mr. A. Howard Clark, editor of the Smithsonian Institution, and Dr. Leonhard Stejneger, curator of reptiles and batrachians, U. S. National Museum.

The printing committee formulated a series of rules for the abbreviation of scientific periodicals in publications of the Smithsonian and its branches. These rules, which have been approved for the use of the Institution and its branches, are given in full in the editor's report. They may be summarized as follows:

1. In abbreviating words in titles, stop before the second vowel, unless the resulting abbreviation would contain but one consonant, in which case stop before the third vowel.

2. All articles, prepositions, and conjunctions are to be omitted, except *and* and *for*, which may be retained when necessary for clearness.

3. In abbreviated titles, the words should follow strictly the order of the full titles.

4. (*a*) Words of one syllable, (*b*) titles consisting of a single word, (*c*) names of towns (except as indicated under rule 5), (*d*) names of persons (when unmodified), and (*e*) names of geological formations are not to be abbreviated.

5. Whenever necessary for clearness any of the foregoing rules may be disregarded, but in such cases words should not be abbreviated.

LIBRARY.

The accessions to the Smithsonian library during the year aggregated 36,068 in volumes and parts, an increase by some 1,800 entries over the previous year. Of these accessions 24,777 were placed in the Smithsonian deposit in the Library of Congress, which comprises in

itself the largest library of scientific works in this country; 3,317 were divided among the libraries of the Secretary's office, the Astrophysical Observatory, the National Zoological Park, and the International Exchanges, as expedient for purposes of administration, and 7,974 were deposited in the United States National Museum library. Besides these, there were numerous additions to the library of the Bureau of American Ethnology, which is administered separately. It is estimated that an equivalent of 6,560 volumes was transmitted to the Library of Congress, comprising in actual numbers 25,524 publications in the form of parts of periodicals, pamphlets, and volumes. These two counts do not include public documents presented to the Smithsonian Institution, sent direct to the Library of Congress as soon as received, without stamping or recording; or public documents and other gifts to the Library of Congress received through the international exchange service, or publications requested to complete sets in the Smithsonian deposit at the Library of Congress, which have been transmitted separately.

As the result of a special effort to secure missing parts to complete sets, 500 new periodicals were added to the lists and about 1,559 parts lacking in the sets were received, which partially or entirely filled up the various series of publications in the Smithsonian deposit. In writing for the missing parts of publications needed to complete these sets the library has had assistance from the international exchange service of the Institution. In addition the Institution has, through the medium of the international exchange service, sent out requests for government documents and serial publications needed to complete the sets in the Library of Congress, and with this end in view letters have been written to Bavaria, the province of Buenos Aires, Costa Rica, Greece, Guatemala, Honduras, Newfoundland, Nicaragua, Japan, Russia, and Salvador. Over 3,300 publications were issued during the year for consultation by members of the staff and by various bureaus of the Government.

In addition to the regular work in the library, the assistant librarian has reconstructed the memorandum list of the engravings and art collection of Mr. George Perkins Marsh, purchased in 1849, whatever catalogue may have been made having been destroyed in the fire of 1866, and has been engaged in preparing a bibliography of aeronautical literature.

PRESERVATION OF ARCHEOLOGICAL SITES.

I have heretofore called attention to what had been done toward the preservation of archeological objects on the public domain from destruction by vandals and relic hunters and toward making these antiquities accessible under proper rules and regulations. Under the terms of an act of Congress approved June 8, 1906, uniform regu-

lations for its administration were prepared by the Secretaries of the Interior, War, and Agriculture, with the cooperation of the Smithsonian Institution, and were promulgated on December 28, 1906, in the form printed in my last report to the Regents. Under rule 8, applications for permits are referred to the Smithsonian Institution for recommendation. During the past year I have acted upon several such applications. The conservation of the nation's archeological possessions was regulated by law none too soon to prevent further mutilation or useless destruction of interesting antiquities in many places.

The President of the United States, by executive proclamation during the year, made several additions to the list of national monuments, including three of archeological interest: (1) the Tonto National Monument in Arizona, where there are two cliff dwellings not yet reported on; (2) the Gila Cliff-Dwellings National Monument in the Gila National Forest in New Mexico, comprising a group of cliff dwellings, and (3) the Grand Canyon National Monument, which includes a large number of cliff dwellings, pueblos, dwelling sites, and burial places in the Grand Canyon of the Colorado.

CASA GRANDE RUIN IN ARIZONA.

In 1906 Congress granted an appropriation of $3,000 to be expended under the supervision of the Secretary of the Smithsonian Institution for the preservation of the Casa Grande ruin in Pinal County, near Florence, Ariz., and for the excavation of the reservation. An account of the work accomplished by Doctor Fewkes up to June 30, 1907, was published in the Smithsonian Miscellaneous Collections under date of October 25, 1907. The work done during the past fiscal year, under a second appropriation, is noted in Appendix II of the present report. The largest structure excavated at Casa Grande is a building 200 feet long with 11 rooms, the massive walls inclosing a plaza. In the central room there is a seat called by the Pima Indians "the seat of Montezuma." The ruins at Casa Grande are found to be very much more extensive than was anticipated, and their permanent preservation is of great archeological importance.

MESA VERDE NATIONAL PARK.

In addition to the work of excavation, preservation, and repair of the cliff dwellings and other prehistoric ruins in the Mesa Verde National Park in Colorado, which was intrusted by the Interior Department to the direction of the Institution in February, 1908, a moderate grant from the Smithsonian fund was approved this year for additional general studies of the prehistoric culture of the Gila

Valley, outside the Casa Grande Reservation. Dr. J. Walter Fewkes, who directed the Mesa Verde explorations, has prosecuted this later research also and will submit an account in detail of what he has done, for publication by the Institution. The work thus far accomplished by Doctor Fewkes is briefly described in Appendix II of the present report.

CORRESPONDENCE.

The correspondence of the Institution, besides serving its purposes in administration, furthers to a degree the second fundamental object of the Institution, the diffusion of knowledge among men. Through this department are received inquiries on the most varied topics relating to almost every field of science, all of which, so far as practicable, are answered by a member of the staff familiar with the subject concerning which information is desired. The Institution however, does not attempt to maintain a universal information bureau, nor does it seek to answer queries of a commercial nature for information which may be secured from a professional advisor upon payment of a fee.

In addition to this general correspondence, there is carried on by the several branches of the Institution a considerable correspondence relating to the respective activities of each. All matters affecting questions of policy, and all appointments, however, receive the personal consideration of the secretary.

During the past year newer and more convenient cases have been installed for filing letters, and certain improvements in methods of indexing and arranging letters have been made.

CONGRESSES AND CELEBRATIONS.

International Zoological Congress.—The Seventh International Zoological Congress met in Boston, August 19 to 25, 1907. Dr. Richard Rathbun, assistant secretary, Dr. Theodore Gill, and Dr. William H. Dall were delegates on the part of the Smithsonian Institution; Dr. F. W. True, Dr. Leonhard Stejneger, and Dr. Harrison G. Dyar on the part of the United States National Museum, and Dr. Frank Baker on the part of the National Zoological Park. These gentlemen were also designated by the Department of State as representatives of the United States Government. In addition, Doctor Gill served as delegate on the part of the Washington Academy of Sciences and the Biological Society of Washington, and to represent His Siamese Majesty. After the Boston meeting the congress paid a visit to Washington from September 3–6, during which time the members were entertained by a trip and luncheon in the National Zoological Park and by an informal reception at the National Museum and the Smithsonian Institution.

International Congress on Tuberculosis.—In connection with the Sixth International Congress on Tuberculosis to be held in the new United States National Museum building in Washington, September 21 to October 12, 1908, the Institution has offered from the Hodgkins fund a prize of $1,500 for the best paper "On the relation of atmospheric air to tuberculosis," mention of which is made elsewhere in this report.

The Secretary of the Institution is a member of the head committee on International Congress on Tuberculosis.

Centenary, London Geological Society.—The centenary celebration of the Geological Society of London was held September 26, 27, and 28, 1907, at which the Smithsonian Institution and the United States National Museum were represented by Dr. Arnold Hague. Doctor Hague reported the gathering of a distinguished body of eminent geologists from all parts of the world.

Mathematical Congress.—The Fourth International Congress of Mathematicians met at Rome, April 6–11, 1908. The Institution was represented by Prof. Simon Newcomb.

Congress of Orientalists.—At the fifteenth session of the International Congress of Orientalists, to be held in Copenhagen, Denmark, August 14–20, 1908, Dr. Paul Haupt, of the United States National Museum and Johns Hopkins University, has been designated to represent the Institution. Upon recommendation of the Institution the following gentlemen have been designated by the Department of State as delegates on the part of the United States Government: Dr. Paul Haupt; Dr. C. R. Lanman, of Harvard University; Prof. Morris Jastrow, jr., of the University of Pennsylvania; and Prof. A. V. W. Jackson, of Columbia University.

Congress of Americanists.—The Sixteenth International Congress of Americanists will be held in Vienna, Austria, September 8–14, 1908. Dr. Franz Boas, of Columbia University, has been named to represent the Institution; and the Department of State, at the suggestion of the Institution, has designated, besides Doctor Boas, the following-named gentlemen delegates on the part of the United States Government: Prof. Marshall H. Saville, of Columbia; Dr. George Grant McCurdy, of Yale; Dr. Charles Peabody, of Harvard; and Dr. Paul Haupt, of Johns Hopkins.

Fishery Congress.—In connection with the International Fishery Congress, to meet in Washington September 22–26, 1908, the Institution made an allotment of $200 from the Smithsonian fund for the best essay or treatise on "International regulation of the fisheries on the high seas; their history, objects, and results."

Other congresses and meetings.—At the meeting of the National Academy of Sciences in New York, November 19–21, 1907, your Secretary presented a brief résumé of some of his special geological

researches in a paper entitled "Summary of studies of Cambrian brachiopods." At the First Pan-American Scientific Congress, to meet in Santiago, Chile, December 25, 1908, to January 5, 1909, Mr. W. H. Holmes, chief of the Bureau of American Ethnology, has been designated by the Department of State, upon the recommendation of the Institution, to represent the United States Government in the section of anthropology and ethnology. Prof. Morris Jastrow, jr., of the University of Pennsylvania, and Dr. Paul Haupt, of the Johns Hopkins University, have been suggested by the Institution as delegates on the part of the United States to the Third International Congress for the History of Religions, to meet at Oxford, September 15–18, 1908. The Institution has subscribed to membership in the First International Congress on Refrigerating Industries to be held in Paris, October 5–10, 1908.

MISCELLANEOUS.

Hamilton fund lecture.—In 1871 a bequest was made to the Smithsonian Institution by Mr. James Hamilton, as follows:

> I give one thousand dollars to the Board of Regents of the Smithsonian Institution, located at Washington, D. C., to be invested in some safe fund, and the interest to be appropriated biennially by the secretaries, either in money or a medal, for such contribution, paper, or lecture on any scientific or useful subject as said secretaries may approve.

The bequest was accepted, but the income was allowed to accrue until it amounted to the principal, the interest of which now gives biennally $240. The first use made of this fund was in 1905, when Dr. Andrew D. White was invited to deliver a lecture on "The diplomatic service of the United States, with some hints toward its reform." Doctor White delivered this lecture in one of the halls of the National Museum in Washington, and it was subsequently printed by the Institution in the Smithsonian Miscellaneous Collections and widely distributed. The second lecture under the auspices of this fund was delivered on Wednesday evening, April 22, 1908, at Hubbard Memorial Hall, Washington, by Dr. George E. Hale, on "Some recent contributions to our knowledge of the sun."

Seismology.—The Institution has received during the year a number of letters and reports on earthquakes in various parts of the world, and has communicated the information therein to Prof. Harry Fielding Reid, of Johns Hopkins University, the representative of the United States on the International Seismological Association. In the Congressional diplomatic appropriation for 1909 there was included the item, "For defraying the necessary expenses in fulfilling the obligations of the United States as a member of the International Seismological Association, including the annual contribution to the expenses of the association, and the expenses of the United States dele-

gate in attending the meetings of the commission, one thousand three hundred dollars." The publications of the Seismological Association are distributed to American correspondents through the medium of the International Exchanges.

Hayden Memorial Medal.—There was presented to the Secretary of the Smithsonian Institution on January 7, 1908, the Hayden memorial geological medal. This gold medal was established by the Philadelphia Academy of Natural Sciences as a memorial of Prof. F. V. Hayden, the eminent geologist and explorer, and was presented to Doctor Walcott in these terms: "In recognition of the value of your individual contributions to geological science and of the benefits derived from your able and conscientious discharge of the official trust confided to you."

NATIONAL MUSEUM.

The operations of the National Museum showing the progress made during the year and the present condition of the collections are discussed in the appendix to the present report and in a separate volume by the assistant secretary in charge, and need not here be taken up in detail.

Over 200,000 anthropological, biological, and geological specimens were received during the year, including many objects of extreme interest. The most important loan addition to the historical collections was the American flag, nearly 30 feet square, which floated over Fort McHenry during the war of 1812 and which was the inspiration for the writing of the verses of the "Star-Spangled Banner," by Francis Scott Key. Relating to ethnology and biology, there were received, as in former years, many important contributions from Dr. W. L. Abbott and Maj. Edgar A. Mearns. Many zoological and botanical specimens have been deposited by the Department of Agriculture, the Bureau of Fisheries, and other government institutions. In geology the most important accessions included the Hambach collection of fossil invertebrates, purchased by the Smithsonian Institution, some rare species of fossil reptiles and mammals from South America, and fossil mammals from Alaska. I may also mention a large series of Cambrian fossils collected by me in British Columbia and Idaho. Specimens of rocks and ores, mainly from the Geological Survey, were added to the collections; also a number of rare minerals.

While the museum is the custodian of government collections, and while to the public its main feature is the exhibition of characteristic objects in its several divisions, yet the law demands that the material shall be classified and properly arranged, a task which involves a large amount of research work. The work during the

past year covered many fields, including prehistoric archeology in Arizona and elsewhere, studies on the human skeleton of different races, physiological and medical observations among the Indians of the Southwest, fossil whales, reptiles of Japan, the Philippines, and North America, corals of the Hawaiian Islands, the study of meteorites from Canyon Diablo, Arizona, and other localities, besides extensive investigations on fossil invertebrates, mammals, reptiles, and plants.

The museum has continued in the customary way to advance the interests of teaching by distributing carefully labeled and classified sets of specimens to educational establishments throughout the country. Twelve thousand specimens were thus distributed during the year.

In conjunction with the Institution the museum participated in the expositions at Jamestown and Bordeaux and much of the material prepared for these occasions has since been incorporated in the museum collections.

On the new building for the National Museum fair progress was made during the year and at its close the walls had been entirely completed and the construction of the roof was well under way. The fitting up of the interior, however, involves a very large amount of work, since it includes the covering with suitable materials of some 10 acres of floor space.

An interesting loan collection of over 650 specimens of laces, embroideries, old and rare pieces of porcelain, enamels, jewelry, and other artistic objects has been temporarily installed in the hall occupied by the gallery of art. These objects were gathered and arranged by an informal committee of ladies, with Mrs. James W. Pinchot as chairman. It is hoped that this exhibit may be the nucleus of a permanent collection of objects of this class.

NATIONAL GALLERY OF ART.

The paintings forming the nucleus of the National Gallery of Art have been exhibited during the past year not under the most favorable circumstances, owing to the Congress not having provided an appropriation for furnishing suitable quarters. Nevertheless, some important donations of pictures were received. Mr. William T. Evans made a number of additions to his collection of contemporary American artists, a deposit of thirteen historical marine paintings by the late Edward Moran was made, and several gifts of single paintings were accepted. By act of Congress approved May 22, 1908, the colossal marble statue of Washington by Horatio Greenough, which since 1875 has occupied its well-known position in front of the Capitol, was transferred to the custody of the Smithsonian Institution.

In order to maintain a proper standard of merit in the acceptance of works of art an advisory committee of five artists has been designated. Three members of this committee were by request selected by three leading art associations of the country and two members were named by the Institution. The committee met at the Smithsonian Institution on April 16, 1908, and organized by the election of Mr. Francis D. Millet as president and Mr. W. H. Holmes, of the Smithsonian Institution, as secretary. The other members of the committee are Mr. Frederick Crowninshield, of the Fine Arts Federation of New York; Mr. Edwin H. Blashfield, of the National Academy of Design; and Mr. Herbert Adams, of the National Sculpture Society.

BUREAU OF AMERICAN ETHNOLOGY.

The Bureau of American Ethnology has continued its investigations among the Indian tribes of the country begun over a quarter of a century ago. While seeking to cover in the most comprehensive manner the whole range of American ethnology, the bureau has taken particular care to avoid entering upon researches that are likely to be provided for by other agencies, public or private. The results sought by the bureau are: (1) Acquirement of a thorough knowledge of the American Indian tribes, their origin, relationship to one another and to the whites, location, numbers, capacity for civilization, claims to territory, and their interests generally, for the practical purposes of government; and (2) the completion of a systematic and well-rounded record of the tribes for historic and scientific purposes before their aboriginal characteristics and culture are too greatly modified or are completely lost.

Since it has not been possible to study all of the tribes in detail, a sufficient number have been taken as types to stand for all. The work accomplished in securing knowledge of these tribes has been recorded in the annual reports of the bureau, and the results obtained have been published, so far as circumstances will permit, in bulletins of the bureau. Many manuscripts are preserved in the archives of the bureau. To the present time there have been collected data relating to some 60 families of linguistic stocks and upward of 300 tribes. During the past year this fund of knowledge was added to through researches carried on in Arizona, New Mexico, Colorado, Texas, Minnesota, Pennsylvania, and Ontario. Investigations in the field, however, were not as extensive as in some previous years, on account of the necessity of retaining nearly all of the ethnologic force in the office for the purpose of completing the Handbook of American Indians, part 1 of which was published last

year. The handbook is in the nature of a summary of knowledge gained thus far concerning the American Indians. The demand for the part of the work published has been so great that the bureau has found it impossible to supply even a third of the copies requested by correspondents. The quota under control of the Superintendent of Documents also was soon exhausted, necessitating the reprinting of an edition of 500 copies (the limit allowed by law) to fill the orders received. As the main body of part 2 was in type at the close of the fiscal year, it is expected that this part will be issued in the course of a few months. In editing the handbook during the year the staff of the bureau was generously aided by upward of thirty specialists throughout the country, who rendered all possible assistance in their particular fields. A work of somewhat similar purpose is a Handbook of American Indian Languages, the manuscript of which was practically completed at the close of the fiscal year.

For the first time the study of native Indian music was seriously taken up by the bureau in connection with certain investigations relating to the grand medicine ceremony of the Chippewa on the White Earth Reservation, Minn. The phonograph was employed in recording the songs. Records of songs were also secured from members of various Indian delegations visiting the capital.

This study and recording of the Indian tribes is not only of national importance but urgent. The native American race, one of the four races of men, is fast disappearing, and the processes of obliteration are sure. If authoritative investigations are not made now, they never can be made with any like degree of accuracy or of thoroughness. It is a work the nation owes to science, to the Indian race, and to itself. It is a work worthy of a great nation, and one which can be carried on systematically only by a nation. Through the researches of the bureau the world is not only securing, while possible, a permanent record of one of the great races of men now dying, but is gaining a knowledge of the Indian for practical purposes of administration and in the interest of humanity.

INTERNATIONAL EXCHANGES.

The promotion of literary and scientific intercourse between this country and other parts of the world has been vigorously carried forward during the past year through the system of international exchanges. The details of the regular work of the service are given in full in the report on the exchange service and only the more important matters are referred to here.

The growth of this service has been made possible through the action of Congress and of our Government in negotiating treaties with other nations to place the exchange of government, scientific, and literary publications upon a definite, legal, international footing.

Through an increase in the appropriation granted by Congress it was possible during the year to inaugurate a system of work which had long been in mind—that of actively seeking returns from foreign countries for the exchanges sent to them by this Government and its departments and bureaus. The result has already been more than satisfactory, but the effort is so recent that its full fruition can hardly be expected within the year. A number of most gratifying acknowledgments have been received from various departments of the Government regarding this new work.

The transmission of packages has been much more prompt during the past twelve months than during any like period in the history of the service, shipments being made to all countries at least once a month.

At the request of the Russian Commission of International Exchanges, on behalf of the library commission of the Douma, the interchange of parliamentary publications has been entered into with Russia.

The French Chamber of Deputies has also made a request, through the Department of State, for the exchange of parliamentary documents, and the matter was communicated to Congress by the department during the last session.

At the time the convention for the exchange of official documents and scientific and literary publications was concluded at Brussels in 1886, an agreement was also entered into between the United States and several other countries for the immediate exchange of official journals, etc., but in the absence of the necessary legislation by Congress no steps have been taken by the Institution to carry this agreement into effect. As the subject has now been brought to the attention of Congress, it is hoped that a sufficient number of copies of the Congressional Record may be set aside for this purpose.

In accordance with treaty stipulations and under the authority of the congressional resolutions of March 2, 1867, and March 2, 1901, setting apart a certain number of documents for exchange with foreign countries, there are now sent regularly to depositories abroad 54 full sets of United States official publications and 32 partial sets, China having been added during the year to the list of countries receiving full sets and Montenegro and Liberia to the list of those receiving partial sets.

As a result of correspondence between the Smithsonian Institution and the diplomatic envoys from the Republic of Liberia, regarding the establishment of a bureau of international exchanges in that country and the interchange of official documents between that country and the United States, the department of state at Monrovia has been designated to act as the exchange intermediary between

the two countries, and the proposition to exchange official publications has been accepted by the envoys.

The total number of packages handled by the International Exchange Service during the past year was 203,098, an increase over the number for the preceding year of 13,268. The weight of these packages was 435,285 pounds, 70 per cent of which was in the interest of the United States Government.

The Smithsonian Institution, through its system of exchanges, is in correspondence with 60,123 establishments and individuals, 48,340 of which are exterior to the borders of the United States. These correspondents are scattered throughout the world, and there are few places, however remote, which do not profit by the service.

NATIONAL ZOOLOGICAL PARK.

By authority of the act of Congress approved April 30, 1890, establishing the National Zoological Park, "for the advancement of science and the instruction and recreation of the people," collections of living animals, now numbering 1,402 individuals, have been brought together from all parts of the world, and housed as nearly as possible in surroundings natural to them. These collections at the close of the fiscal year included 350 species: Mammals, 146; birds, 168; and reptiles, 36.

By exhibiting the animals, properly labeled, the object of instructing and entertaining the visitors, of which there were 652,500 (including 4,638 school children) during the year, was furthered, and by study of the specimens the advancement of science was in a measure attained. In September the park was visited by the International Zoological Congress, about eighty members of which spent a day examining the collections. As in previous years specialists of the Department of Agriculture studying animal diseases were offered opportunities for pathological investigations when animals died, and such dead animals as might be useful to the national collections were sent to the National Museum. This to a certain degree was in keeping with the first purpose in establishing the park, namely, "the advancement of science." It has not as yet been possible, however, owing to the yearly present necessities, to fully carry out plans in this regard formulated at the time of the organization of the park.

Designs have been drawn for a much-needed laboratory and hospital building, through the erection and equipment of which it is hoped not only that the welfare of the Government's animals may be even more thoroughly guarded, but investigations of a zoological nature for the increase of practical and scientific knowledge may be prosecuted. With one exception no particular appropriation has been made for

the erection of buildings for the animals in the park since its establishment. The wooden structures which originally sheltered the animals could therefore be replaced only as strict economy in administration expenses permitted. As the appropriations for administration for a number of years have been but little more than sufficient to maintain the park, it can not now be said how soon the plans for the new building may be carried into effect. There is also needed a new aquarium building, since the present structure, originally built in the most temporary manner for use as a hay shed, is fast falling into decay, and a general aviary, antelope house, inclosures for sea lions and seals, and a centrally located office building are much desired.

Under the special appropriation allowed for the reconstruction and repairing of walks and roadways the most notable improvements of the year have been made, several long concrete approaches having been constructed, and a considerable portion of roadbed having been remade. As in previous years, particular attention has been devoted to preserving the natural beauty of the grounds.

During the year there were 591 accessions, which included 68 gifts, 91 births, 397 purchases, and 32 exchanges. There were 382 losses, by death, exchange, and return of animals. Total number June 30, 1908, 1,402.

ASTROPHYSICAL OBSERVATORY.

The work of the Astrophysical Observatory during the last fiscal year has consisted (1) of solar observations on Mount Wilson, California, and at Washington, (2) a solar eclipse expedition to Flint Island in the southern Pacific, and (3) the final preparation and publication of the second volume of the Annals of the Observatory.

The Mount Wilson observations, continued from the summers of 1905 and 1906, were directed toward securing as many records of intensity of solar radiation as possible for the study of solar changes. As in former years, other kinds of measurements were made, notably on the brightness of the sky and on the reflection of the clouds. Since the observations as a whole have shown that the variation of solar radiation is highly probable, and since numerous days suitable for solar radiation measurements were found in the months from May to November on Mount Wilson, it is proposed to erect, on a small and well-isolated plot of ground leased for the purpose, a fireproof observing shelter to be occupied by Smithsonian observers each year during the months mentioned. This will enable frequent observation of the "solar constant" during a period of years at least equal to the sun-spot cycle, a research regarded as of great importance by the late director, Mr. Langley. The work at Washington included the observation, with improved methods, of the relative brightness of

different parts of the sun's disk, and preliminary measurements, requiring exceptional care, of the absorption of water vapor in long columns of air, for the region of the spectrum where rays are chiefly emitted by the earth.

The Smithsonian expedition to Flint Island in the southern Pacific to study the solar eclipse of January 3, 1908, was made in cooperation with Director Campbell, of the Lick Observatory, the party being absent from Washington from November 5, 1907, to February 12, 1908. It was proposed to measure, with that extremely sensitive electrical thermometer called the bolometer, the intensity of the radiation of the solar corona, and to determine the quality of coronal light as compared with sunlight. This is an observation that it is very unlikely will ever be possible except during an eclipse. In general terms the bolometric results indicate that the coronal radiation differs but little in quality from that of the sun, and is in fact far richer than the reflected rays of the moon in visible light, although less rich than skylight. Observations as to the nature of the corona were such as to lead at least to the suggestion that gases are present along with solid and liquid particles. The exact conclusions reached are given fully in the report of the director.

The second volume of the Annals, issued in April, includes an account of the work of the Observatory from 1900 to 1907. Commendatory notices by letter and in the journals and requests for copies of the work have been numerous. Speaking broadly, the energy of the Observatory was devoted, during the period covered by the volume, to an investigation of the intensity of the rays of the sun and the dependence of the earth's temperature upon the radiation. The investigations have resulted in apparently definitely fixing the approximate average value of the "solar constant" at 2.1 calories per square centimeter per minute, and in showing decisively that there is a marked fluctuation about this mean value sufficient in magnitude to influence very perceptibly the climate, at least of the inland regions, upon the earth.

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

The organization known as the International Catalogue of Scientific Literature has by means of the cooperation of all of the principal countries of the world been publishing since 1901, in seventeen annual volumes, a classified author's and subject index catalogue of the current scientific literature of all the civilized countries of the world. Each country collects, indexes, and classifies the scientific literature published within its borders and furnishes to the central bureau in London the material thus prepared for publication in the

annual volumes. The cost of preparation is borne by the countries taking part in the enterprise, in the great majority of cases the support being derived through direct governmental grants. The entire cost of printing and publishing is borne by the subscribers to the catalogue, which include, besides individuals, the leading American universities, libraries, and scientific societies.

That all sections of the civilized world are now represented in this enterprise is shown by the following list of regional bureaus now established and regularly furnishing the London central bureau classified citations of scientific papers published within their domains: Austria, Belgium, Canada, Cuba, Denmark, Egypt, Finland, France, Germany, Greece, Holland, Hungary, India and Ceylon, Italy, Japan, Mexico, New South Wales, New Zealand, Norway, Poland (Austrian, Russian, and Prussian), Portugal, Queensland, Russia, South Africa, South Australia, Spain, Sweden, Switzerland, United States of America, Victoria, and Western Australia.

During the year there was combined with the International Catalogue of Scientific Literature the annual publication known as the Zoological Record, which has been prepared for many years by the Zoological Society of London. This, it is hoped, is merely preliminary to the association of a number of independent scientific bibliographies and yearbooks with the International Catalogue of Scientific Literature.

Under the congressional allotment of $5,000 for the last fiscal year, as in previous years, 28,528 references to American scientific literature were completed and forwarded to the central bureau in London for publication.

Respectfully submitted.

CHARLES D. WALCOTT,
Secretary.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

SIR: I have the honor to submit the following report on the operations of the United States National Museum for the fiscal year ending June 30, 1908:

The ever-increasing crowded condition of the two buildings occupied by the National Museum has made it more difficult each year to provide for the collections and to insure their safety and orderly arrangement. It is, therefore, but natural that the completion of the large new building, with its greater conveniences, should be eagerly awaited, and it is hoped that the work of moving in can begin before the close of another year. At the commencement of the fiscal year the outer walls of this structure had been carried to the height of the lintels at the top of the second story on the eastern section of the building, but not so high on the western. Work on the two entrance pavilions had only reached the top of the basement story, but the steel work and arches of the second floor were in place, and the lecture hall in the basement had been inclosed and partly vaulted.

Fair progress was made during the year, and at its close the walls had been entirely completed except at the south pavilion, which is to contain the main entrance and the rotunda, and the construction of the roof was well under way. The fitting up of the interior, however, involves a very great amount of work, since it includes the covering with suitable materials of some 10 acres of floor space, the building of many partitions, the plastering of walls, piers, and ceilings, and the introduction of boilers, machinery, and minor appliances for heating, ventilation, lighting, and various other purposes, besides the furnishings for the halls and rooms.

The buildings occupied for many years have been kept in excellent condition, and the museum building has been much improved by replacing its original and imperfect roofs, which have always been a source of great annoyance. The rebuilding of these roofs with tin, begun three years ago, was, with the exception of that covering the rotunda, completed during the year. The latter, however, has since been finished. It is interesting to note that this entire work was carried on without closing any part of the building and without injury to any of its contents. Some progress was also made in the isolation of the exhibition halls by the closing of the large openings between them, as a precautionary measure against the spread of fire.

The failure to secure, last winter, an appropriation for fitting up suitable quarters for the nucleus of the national gallery of art has retarded the segregation and arrangement of the collection of paintings, which is now exhibited under very adverse conditions, not at all likely to attract the attention of those who might gladly contribute to this popular branch of the museum. Notwithstanding these circumstances, however, some important donations of pictures were received during the year.

Mr. William T. Evans has added to his collection of contemporary American artists paintings by Hugo Ballin, George De Forest Brush, F. S. Church, Henry Golden Dearth, Charles Melville Dewey, Paul Dougherty, Ben Foster, Childe Hassam, Ernest Lawson, Willard Leroy Metcalf, Robert Reid, R. M. Shurtleff,

John H. Twachtman, Henry Oliver Walker, Worthington Whittredge, Carleton Wiggins, Irving R. Wiles, and Frederick Ballard Williams. Among other gifts of paintings to the gallery may be mentioned the following: "Crossing the Ferry," by Adrien Moreau, presented by Mrs. James Lowndes in memory of her father, Lucius Tuckerman; and "Indian Summer Day," by Max Weyl, presented by 30 of his Washington friends in commemoration of the seventieth anniversary of the artist's birth.

The collection of 13 historical marine paintings executed by the late Edward Moran during the later years of his life, have, through the courtesy of Mr. Theodore Sutro, of New York, been temporarily deposited in the gallery, of which they form a conspicuous feature. The titles of the several pieces of the series are as follows: The Ocean—The Highway of all Nations; Landing of Lief Erickson in the New World in the Year 1001; The Santa Maria, Nina, and Pinta; The Debarkation of Columbus; Midnight Mass on the Mississippi Over the Body of Ferdinand De Soto, 1542; Henry Hudson Entering New York Bay, September 11, 1609; Embarkation of the Pilgrims from Southampton, August 5, 1620; First Recognition of the American Flag by a Foreign Government, in the Harbor of Quiberon, France, February 13, 1778; Burning of the Frigate Philadelphia in the Harbor of Tripoli, February 16, 1804; The Brig Armstrong Engaging the British Fleet in the Harbor of Fayal, September 26, 1814; Iron versus Wood—Sinking of the Cumberland by the Merrimac, in Hampton Roads, March 8, 1862; The White Squadron's Farewell Salute to the Body of Captain John Ericsson, New York Bay, August 25, 1890; Return of the Conquerors, Typifying Our Victory in the Late Spanish-American War, September 29, 1899.

By act of Congress, approved May 22, 1908, the colossal marble statue of Washington by Horatio Greenough, completed in 1840, and since 1875 occupying its well-known position in front of the main steps of the Capitol, was transferred to the custody of the Smithsonian Institution. It is intended to remove this work at once to the Smithsonian building, where it will be installed for the present.

In accordance with the plan proposed the year before, with the object of maintaining a proper standard of merit in the acceptance of paintings and works of sculpture for the National Gallery of Art, a committee of five artists to act in an advisory capacity was designated in the spring of 1908. The selection of three members of the committee was requested of three leading art associations, the other two members being named by the Institution. This committee held its first meeting, for the purposes of organization and preliminary considerations, at the Smithsonian Institution, on April 16, 1908. As organized, it is constituted as follows: Mr. Francis D. Millet, president; Mr. Frederick Crowninshield, representing the Fine Arts Federation, of which he is the president; Mr. Edwin H. Blashfield, representing the National Academy of Design; Mr. Herbert Adams, representing the National Sculpture Society, of which he is the president; and Mr. William H. Holmes, of the Smithsonian Institution, secretary of the committee.

In May, 1908, a number of the ladies of Washington, acting on their own initiative but with the hearty concurrence of the Institution, effected an informal organization looking to the building up in the National Museum of a worthy collection of laces, embroideries, and other artistic objects of personal adornment and utility. Having decided that the assembling of a loan collection might best further their efforts by stimulating an interest in the subject, a working committee, with Mrs. James W. Pinchot as chairman, was immediately appointed, and during May and June a very large number of appropriate objects was brought together. The installation, made by the members of the committee, filled twenty cases, which had unfortunately to be placed in the very

crowded hall occupied by the gallery of art. The character of the articles and the very effective manner in which they were arranged has, however, made this collection one of the most attractive features of the museum. The number of exhibitors is 18, while the total number of their contributions amounts to over 650. Besides laces and embroideries, the exhibit contains many fans, miniatures, old and rare pieces of porcelain and china, enamels, ivories, silverware, and jewelry. It is hoped that this beginning, which, it is understood, will be extended during the coming winter, will go far toward accomplishing the result so much desired.

ADDITIONS TO THE COLLECTIONS.

The total number of accessions received during the year was 1,391, comprising approximately 219,505 specimens, of which 10,487 were anthropological, 176,263 biological, and 32,755 geological.

The principal accession in ethnology consisted of about 600 extremely interesting objects collected among the natives of West Borneo by Dr. W. L. Abbott, and by him presented to the museum, in continuation of his many valuable contributions from the Malaysian region. Other important ethnological collections from the islands of the South Pacific were also obtained, among which may be mentioned material from the Philippine Islands presented by Maj. E. A. Mearns and Capt. Jesse R. Harris, U. S. Army; and from Guam, donated by Mr. W. E. Safford. Noteworthy among the loans are a large number of art objects in metal obtained by Gen. Oliver Ellsworth Wood, U. S. Army, during a four years' residence in Japan as military attaché, and a collection made by Senator A. J. Beveridge during an extended trip to the Orient, including the Philippine Islands, Japan, and China. As bearing upon the American Indians there were added many specimens from the region of the northern cliff dwellers of northwestern Arizona, the Taos and Zuñi Indians of New Mexico, and the Iroquois of New York and Canada. A small but valuable collection illustrating the industrial and social life of the little-known Tahltan Indians of Stikine River, British Columbia, was received from the Bureau of American Ethnology. Among the models from the Patent Office assigned to the division of ethnology were many relating to fire making, heating, cooking, illumination, culture history, etc.

To Mr. Ephraim Benguiat, of New York, the museum is under deep obligations for the addition of twenty-one objects to his already large collection of Jewish religious ceremonial objects on deposit in the division of historic religions. They include two finely embroidered synagogue veils, two silver-gilt breastplates of exquisite workmanship, and a silver and brass hanukah lamp of artistic design.

The division of prehistoric archeology obtained from the excavations conducted by Dr. J. W. Fewkes at the Casa Grande ruins, Arizona, from October, 1906, to March, 1907, under a special act of Congress, an especially valuable collection, comprising stone implements, pottery, articles of shell and bone, wooden implements and timber, textile fabrics, and basket work, and a number of human skulls and parts of skeletons. Important additions were also received from other parts of this country, and from Mexico, Bolivia, Egypt, and India.

The additions to the division of physical anthropology were numerous and from many sources, illustrating several races of the human family both living and extinct. Dr. W. L. Abbott also contributed a large series of specimens illustrative of the anthropoid apes and the monkeys of West Borneo and Sumatra. Many photographs, facial casts, and measurements of the Indians of North America were made in the laboratory.

The division of technology was greatly enriched by the transfer from the Patent Office of many models and original examples of inventions interesting historically. The subject of firearms is most fully represented in the collection, which, however, also includes printing presses, sewing machines, typewriters, electrical inventions, steam machinery, time bank locks, looms, spinning and knitting machinery, etc. Another notable accession to this division consisted of about 150 pieces of apparatus devised and used by Dr. Alexander Graham Bell in his earliest telephone experiments. To the War Department, and also personally to Col. A. H. Russell, U. S. Army, the museum is indebted for several interesting examples of firearms.

The collection in the division of history was increased by many valuable loans and gifts. By far the most noteworthy object among the loans was the flag which floated over Fort McHenry during its bombardment by the British fleet on the night of September 13–14, 1814, and made famous as the "Star Spangled Banner" by the verses of Francis Scott Key, an eyewitness of the fight. This flag, retained by Col. George Armistead, the commander of the fort, descended to his grandson, Mr. Eben Appleton, of New York, who has most generously allowed it to be exhibited to the public. It is much tattered and worn, and measures 32 feet 10 inches long by 27 feet 6 inches wide. A collection of 175 pieces of Lowestoft china and cut glass, used at Mount Vernon in the time of Washington, was deposited by Miss Nannie R. Heth. Among the bequests may be mentioned a gold-mounted sword and a silver pitcher presented to J. Bankhead Magruder by citizens of Virginia and Maryland, and a gold ring given by Richard Somers to Stephen Decatur just before the heroic death of the former on the *Intrepid* in the war with Tripoli in 1804. The collections of the Colonial Dames of America and of the Daughters of the American Revolution were both increased by the addition of a number of interesting objects.

Miss E. R. Scidmore deposited 92 pieces of porcelains and some bronze, jade, and lacquer objects. Fifteen musical instruments were presented, mostly of primitive origin, though some are of historical interest. The principal additions in graphic arts were contained among the models from the Patent Office, consisting mainly of early devices now of extreme interest in illustrating the history of photography.

The department of biology received, as in former years, important contributions, chiefly of mammals and birds, from Dr. W. L. Abbott and Dr. E. A. Mearns, U. S. Army, the former making collections in Sumatra and southwestern Borneo, the latter in the Philippine Islands. Especially interesting for the purposes of comparison as well as for exhibition, was a series of 166 antlers and 26 scalps of the American elk, some of unusual size, from the State of Wyoming.

In most of the other zoological groups the additions were extensive and representative of many parts of the world. Mr. Robert Ridgway, who spent about four months in Costa Rica collecting material and information for use in connection with his monograph on the birds of North and Middle America, brought back a large number of specimens. The Bureau of Fisheries made important transfers of both fishes and marine invertebrates, largely obtained during the explorations of the steamer *Albatross* in the Pacific Ocean. The collection of insects was increased by about 53,000 specimens, mostly American, although valuable contributions were also received from Europe.

Through recent acquisitions, the division of mollusks now possesses authentically named specimens of 1,330 species of the land shells of the Philippine Islands, of which about 1,500 species have been described. The transfer to Washington from the museum of Yale University of the main part of the col-

lections of marine invertebrates obtained during the early seacoast work of the Bureau of Fisheries, and placed in the care of Prof. A. E. Verrill for study and description, has added a large number of types and a still greater number of species not previously represented in the museum.

The collection in helminthology has reached a position of much practical importance, since it contains a great deal of material resulting from government investigations on the diseases of man and of wild and domestic animals. These specimens have been mainly obtained through the Marine-Hospital Service, the Bureau of Animal Industry, and the Bureau of Fisheries. The rapid growth and exceptionally fine condition of the collection are due to the efforts of representatives of the two bureaus first mentioned, who are in charge of the subject.

The division of plants received a total of about 25,000 specimens, mainly collected in North and Central America, the largest accessions coming from the Department of Agriculture. Much valuable material was also derived from the explorations of Dr. J. N. Rose in the southwestern United States and northern Mexico.

In the department of geology the most important accessions were of fossil invertebrates, some of which were especially large and noteworthy. Among them may be mentioned the celebrated Gustav Hambach collection, purchased by the Smithsonian Institution; the Gilbert collection of Niagaran fossils from northern Indiana; a very large series of Cambrian fossils, resulting from explorations in British Columbia and Idaho during the summer of 1907 by Secretary Charles D. Walcott; many recently described specimens deposited by the United States Geological Survey; extensive collections from the Paleozoic formations of Tennessee and Virginia, made by Doctor Bassler; and valuable exchanges from Germany and France.

Of fossil vertebrates there were two especially important additions. One consisted of a large number of rare species of reptiles and mammals from various horizons in the United States and South America, obtained through exchange with the American Museum of Natural History; the other of the remains of several species of fossil mammals, in a more or less fragmentary condition, collected by Mr. Gilmore on the Smithsonian expedition to Alaska. Among other additions to the department were series of rocks and ores, mainly from the Geological Survey, a number of rare minerals, and three meteorites.

CARE AND CLASSIFICATION OF THE COLLECTIONS.

As collections are received at the museum they are assigned to the divisions to which they belong, and are at once labeled and recorded as to their origin, in order to insure their identity and future usefulness. The work of classification and systematic arrangement which follows requires the naming of the objects or specimens, entailing extensive studies which often result in important contributions to knowledge. The staff of employees directly connected with the handling of the collections has always been much too small to perform this duty in a thoroughly satisfactory manner, and, while the safety of the collections has been secured by constant vigilance, it can not be said that their maintenance has been all that was desirable. These conditions may, of course, be largely attributed to the inadequate quarters afforded, but many of the difficulties arising from this cause might readily have been overcome with a greater force of helpers.

The routine work of caring for the collections is the same from year to year, and scarcely merits repetition in this connection. There was the customary overhauling and cleaning of the dried specimens and of the drawers and cases

containing them; the frequent poisoning of many thousands of objects subject to destruction by insect pests, and the renewal of alcohol on liquid preparations, or the filling up of tanks, jars, and vials from which the preservative had more or less evaporated. The labeling and cataloguing of individual specimens as identified went on continuously, and, besides, there was the preparation of specimens for the reserve series and exhibition halls, the selection and arrangement of duplicates for distribution, and the identification of material received from several hundred persons, as happens every year.

Of investigations conducted during the year mention may be made of detailed studies on the examples of basketry and traps contained in Doctor Abbott's collection from southwestern Malaysia by Prof. O. T. Mason, who also prepared a paper entitled "Vocabulary of Malaysian basketwork." Dr. Walter Hough completed a paper on the manufacture of pulque wine and began a study of the Malaysian blowguns received from Doctor Abbott. The Jewish ceremonial objects in the National Museum were described and illustrated by Dr. Cyrus Adler and Dr. I. M. Casanowicz, and the latter has in progress an account of the collection of rosaries. In prehistoric archeology investigations were conducted by Mr. William H. Holmes and Dr. J. W. Fewkes. Dr. Ales Hrdlička continued his studies on the human skeleton of different races and completed a manuscript entitled "Physiological and medical observations among the Indians of the Southwest and northern Mexico."

The principal researches based upon the collections in biology related to the following subjects: The fossil cetaceans of North America; the birds of North and Middle America; the reptiles of Japan, the Philippine Islands, and North America; the mosquitoes of North and Central America and the West Indies; the mollusks and bracniopods of the eastern Pacific Ocean collected by the Fisheries steamer *Albatross;* crustacea from East Africa and the Antarctic Ocean; the crinoid collection of the museum; the corals of the Hawaiian Islands; animal parasites; and the cacti, ferns, and other groups of plants. In addition to the above many collections were being studied for the museum by specialists attached to other institutions.

The material obtained during his visit to Meteor Crater, Canyon Diablo, in May, 1907, was the subject of investigation by Dr. George P. Merrill, according to whose conclusions the well-known and peculiar depression existing there was caused by impact, presumably of a large meteor. Studies were also conducted on the meteorites in the museum collection by Doctor Merrill, assisted by Mr. Wirt Tassin. Extensive investigations were carried on by Dr. R. S. Bassler on fossil invertebrates, by Mr. J. W. Gidley on fossil mammals, by Mr. C. W. Gilmore on fossil reptiles, and by assistants of the Geological Survey on fossil plants.

EXHIBITION COLLECTIONS.

For some years past there has been no opportunity to increase the exhibition collections, except in a very limited way, for in nearly all the halls the cases are so crowded as to interfere with the circulation of visitors and objects can not be viewed to advantage. This does not mean, however, that these collections require any less attention than before, since their maintenance demands constant oversight and labor. Moreover, changes are often made by replacing older collections with others more recently acquired and of greater present interest.

From the new material obtained for the Jamestown Exposition and returned during the winter, as many articles as possible were placed on exhibition. The loan collections of General Wood and Senator Beveridge were installed in

the west hall. The Abbott cases in the gallery of the same hall were rearranged, and the entire Philippine collection, as far as it has been prepared for exhibition, was placed in the gallery of the Pueblo court. The objects of Jewish religious ceremonial from Mr. Benguiat were incorporated in the collection previously received from him. A special case of Egyptian antiquities and a series of Egyptian (Coptic) textiles were arranged, and additions were made to the Bible collection. In the divisions of technology and history places were found for nearly all of the objects obtained. The interesting series of portraits of distinguished physicians, prepared for the Jamestown Exposition, was installed with the collection of medicine, and the loan collection of Miss Scidmore, on the ceramic gallery.

The principal additions to the exhibition series of the department of biology consisted of a skeleton of Baird's beaked whale, a rare species, and of a group of polar bears obtained on the Ziegler arctic expedition and presented by Mrs. Ziegler. The exhibit of insects, which has been in preparation for some time, was completed to the extent permitted by the space available. In the exhibition halls of the department of geology comparatively few additions or changes were made.

MISCELLANEOUS.

Duplicate specimens, mostly biological and geological, separated from the collections during the progress of investigations were disposed of to the number of about 26,000. About 14,000 of these were used in making exchanges with establishments and individuals both at home and abroad, whereby the collections of the museum received new material to approximately the same extent. The other 12,000 specimens were utilized in the customary way to advance the interests of teaching, having been distributed in carefully labeled and classified sets to educational establishments throughout the country. Besides the above, over 9,000 specimens were sent to specialists for study, partly for the publications of the museum and partly to aid in work carried on under other auspices.

The total number of visitors to the public halls was about 300,000, a daily average of over 960 persons. This is to be regarded as a large attendance, considering that the buildings are opened only on week days and during official hours. That the National Museum is not serving its full purpose in this direction, however, is evidenced by the experiences of museums in other large cities, where evening and Sunday opening insures a very much greater attendance by extending to the working people the opportunity of examining the collections.

The publications of the year comprised the annual report for 1907, volumes 32 and 33, and part of volume 34 of the proceedings, five volumes of bulletins, and several papers belonging to the contributions from the national herbarium, all of which, except the annual or administrative report, are descriptive of museum collections.

The library of the museum contains 33,564 volumes, 52,112 unbound papers, and a number of manuscripts, the additions during the year having consisted of 3,257 books, 1,470 pamphlets, and 247 parts of volumes. This library is a purely technical one, confined to that class of publications bearing upon the subjects covered by the museum collections, but its means of increment are so limited as to make it very difficult to keep up those studies which are essential to the classification of the collections. The appropriation for the purchase of books is entirely inadequate, and, in fact, the principal increase is effected through exchanges and gifts.

During the summer of 1907 the museum, in conjunction with the Institution, participated in the Jamestown Tercentennial Exposition, and the International Maritime Exposition at Bordeaux, France, the arrangements for which were

described in the last report. The exhibit at the former exposition was designed to illustrate the aboriginal, colonial, and national history of America, while the entire collection sent to Bordeaux by the Government was assembled, installed, and maintained under the direction of the Smithsonian Institution, represented by Mr. W. de C. Ravenel, administrative assistant of the museum. The display at Jamestown contained many new groups and series of objects specially prepared or obtained for the purpose, which have since been incorporated in the museum collections.

Respectfully submitted.

RICHARD RATHBUN,
Assistant Secretary, in charge of U. S. National Museum.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix II.

REPORT ON THE BUREAU OF AMERICAN ETHNOLOGY.

Sir: I have the honor to submit the following report on the operations of the Bureau of American Ethnology for the fiscal year ending June 30, 1908:

SYSTEMATIC RESEARCHES.

The operations of the Bureau of American Ethnology for the fiscal year ending June 30, 1908, conducted in accordance with the act of Congress making provision for continuing researches relating to the American Indians under direction of the Smithsonian Institution, were carried forward in conformity with the plan of operations approved by the Secretary May 25, 1907.

As in previous years, the systematic ethnologic work of the bureau was intrusted mainly to the regular scientific staff, which comprises eight members. This force is not large enough, however, to give adequate attention to more than a limited portion of the great field of research afforded by the hundreds of tribes, and the bureau has sought to supply the deficiency in a measure by enlisting the aid of other specialists in various branches of the ethnologic work. By this means it is able to extend its researches in several directions at a comparatvely modest outlay. While seeking to cover in the most comprehensive manner the whole range of American ethnology, the bureau has taken particular care to avoid entering upon researches that are likely to be provided for by other agencies, public or private. The results sought by the bureau are: (1) Acquirement of a thorough knowledge of the tribes, their origin, relationship to one another and to the whites, location, numbers, capacity for civilization, claim to territory, and their interests generally, for the practical purposes of government; and (2) the completion of a systematic and well-rounded record of the tribes for historic and scientific purposes before their aboriginal characteristics and culture are too greatly modified or are completely lost.

During the year researches were carried on in Arizona, New Mexico, Colorado, Texas, Minnesota, Pennsylvania, and Ontario. Investigations in the field were more than usually limited on account of the necessity of retaining nearly all of the ethnologic force in the office for the purpose of completing the revision of their various articles for the second part of the Handbook of American Indians, and in preparing additional articles on subjects overlooked in the first writing or that are based on data recently collected.

The chief remained in the office during nearly the entire year, dividing his time between administrative duties and ethnologic investigations and writing. The completion of numerous articles for the second part of the Handbook of American Indians, the revision of reports and bulletins, and the examination of various manuscripts submitted for publication especially claimed his attention. Aside from these occupations, his duties as honorary curator of the division of prehistoric archeology in the National Museum and as curator of the National Gallery of Art absorbed a portion of his time. During the year much attention was given to the collections of the division of prehistoric archeology in the National Museum, especially to their classification with the view of removal in

the near future to the new National Museum building. In the same connection the chief carried forward the preparation of his Handbook on the Stone Implements of Northern America.

In October the chief was called on to make an official visit to the Jamestown Exposition for the purpose of examining the exhibits of the Institution and superintending necessary repairs. In April he was assigned the very pleasant duty of visiting Detroit, Mich., in company with the Secretary, for the purpose of inspecting the great collection of art works recently presented to the Smithsonian Institution by Mr. Charles L. Freer. On this occasion he availed himself of the opportunity of examining the interesting collections of art and ethnology preserved in the Detroit museum of art.

In June the chief was selected to represent the Institution as a member of the delegation of Americans appointed by the Department of State to attend the Pan-American Scientific Congress to be held in Santiago, Chile, beginning December 25, 1908, and he began at once the preparation of a paper to be read before the congress, the subject chosen being "The Peopling of America."

At the beginning of the year Mrs. M. C. Stevenson, ethnologist, was in the office engaged in preparing reports on her recent researches in the field. Her work at Taos, Santa Clara, and other Rio Grande pueblos was not so well advanced as to admit of final treatment, but progress was made in the classification and elaboration of the data thus far collected. Principal attention was given while in the office to the completion of papers relating to the medicinal and food plants of the Zuñi Indians, the pantheon of the Zuñi religious system, the symbolism of Pueblo decorative art, and the preparation of wool for weaving among the Pueblo and Navaho tribes.

On May 28 Mrs. Stevenson again took the field in the Rio Grande Valley with the view of continuing her investigations among the Taos, Santa Clara, San Ildefonso, and other Pueblo groups, and at the close of the year she was able to report satisfactory progress in this work.

Mr. F. W. Hodge, ethnologist, was engaged during the year on the Handbook of American Indians, the editorial work of which has proved extremely arduous and difficult. This work is in two parts: Part 1, A–M, was issued from the press in March, 1907, and the edition became practically exhausted in a few months. Indeed the demand for the work has been so great that the bureau has found it impossible to supply even a third of the copies requested by correspondents. The quota under control of the Superintendent of Documents also was soon exhausted, necessitating the reprinting of an edition of 500 copies (the limit allowed by law) in order to fill the orders received. The main body of part 2 was in type at the close of the fiscal year, and about 250 pages had been finally printed, though progress in proof reading was exceedingly slow on account of the great diversity of the topics treated and the difficulty of preparing or of bringing to date numbers of articles relating often to obscure tribes and subjects. It is expected that the second part will be ready for distribution during the coming winter. In the editorial work Mr. Hodge had the assistance of all the members of the staff of the bureau, and especially of Mrs. Frances S. Nichols, who devoted her entire time to the task. In addition the following specialists rendered all possible assistance in their particular fields: Mr. S. A. Barrett, of the University of California; Rev. W. M. Beauchamp, of Syracuse; Dr. Franz Boas, of Columbia University; Dr. Herbert E. Bolton, of the University of Texas; Mr. D. I. Bushnell, jr.; Dr. Alexander F. Chamberlain, of Clark University; Mr. Stewart Culin, of the Brooklyn Institute Museum; Dr. Roland B. Dixon, of Harvard University; Dr. George A. Dorsey, of the Field Museum of Natural History; Mr. J. P.

Dunn, of Indianapolis; Mr. Wilberforce Eames, of the New York Public Library; Lieut. G. T. Emmons, U. S. N.; Dr. Livingston Farrand, of Columbian University; Miss Alice C. Fletcher, of Washington; Mr. Gerard Fowke, of St. Louis; Mr. Merrill E. Gates, of the Indian Rights Association; Mr. William R. Gerard, of New York; Dr. P. E. Goddard, of the University of California; Dr. George Bird Grinnell, of New York; Mr. Henry W. Henshaw, of the United States Biological Survey; Dr. Edgar L. Hewett, of the Archæological Institute of America; Dr. Walter Hough and Dr. Aleš Hrdlička, of the United States National Museum; Dr. William Jones, of the Field Museum of Natural History; Dr. A. L. Kroeber, of the University of California; Mr. Francis La Flesche, of Washington; Dr. A. B. Lewis, of the Field Museum of Natural History; Dr. Charles F. Lummis, of Los Angeles; Dr. O. T. Mason, of the United States National Museum; Mr. Joseph D. McGuire, of Washington; Rev. Leopold Ostermann, of Arizona; Mr. Doane Robinson, of the South Dakota Historical Society; Mr. Edward Sapir and Mr. Frank G. Speck, of the University of Pennsylvania; Mr. C. C. Willoughby, of the Peabody Museum, Cambridge; and Dr. Clark Wissler, of the American Museum of Natural History. I take this occasion to express the appreciation of the bureau for the valuable aid so generously rendered by these students, without which it would not have been possible to make the work either as complete or as accurate as it is.

Throughout the year Mr. James Mooney, ethnologist, remained in the office, occupied either in the preparation of articles intended for the second part of the Handbook of American Indians or in preparing answers to ethnologic inquiries made by correspondents of the bureau. His principal work for the handbook was an elaborate and detailed study of the numerical strength of the aboriginal population north of Mexico from the time of their first contact with the whites. This important foundation study of American ethnology has never before been undertaken in a systematic and comprehensive manner, and the result proves of much scientific interest. Contrary to the opinion frequently advanced on superficial investigation, the Indians have not increased in number since their first contact with civilized man, but have decreased by fully two-thirds, if not three-fourths. California alone, the most populous large section during the aboriginal period, contained probably as many Indians as are now officially recognized in the whole United States. The causes of decrease in each geographic section are set forth in detail in chronologic sequence in Mr. Mooney's study.

During the year Dr. John R. Swanton, ethnologist, was occupied entirely with work in the office, principally in connection with the Indian languages of Louisiana and Texas. He finished the analytic dictionary of the Tunica language and compiled similar dictionaries of Chitimacha, Attacapa, and Tonkawa. All the extant Comecrudo and Cotoname material, as well as the material pertaining to related tribes contained in Fray Bartholome Garcia's Manual para administrar los sacramentos (Mexico, 1760), was similarly arranged, and in addition a comparative vocabulary was constructed which embraces the last-mentioned data as well as the Karankawa and Tonkawa. During the months of May and June another dictionary was prepared, embracing all the Biloxi linguistic material collected by Doctor Gatschet and Mr. J. O. Dorsey in 1886, 1892, and 1893. The material in this last work is exceptionally full and complete. The Comecrudo and Cotoname, the material extracted from Garcia's catechism, and the Biloxi, are nearly ready for the press. The languages referred to above, with the addition of the Natchez, include practically all of those in the eastern and southern United States that are in immediate danger of extinction. The information regarding most of them is very limited, and

in order that the precious material may not by any misadventure be destroyed, it should be published at an early date.

Besides work strictly linguistic, Doctor Swanton had in hand a paper on the tribes of the lower Mississippi Valley and neighboring coast of the Gulf of Mexico. This can not be completed, however, until additional researches among the tribes in question have been made.

Dr. J. Walter Fewkes, ethnologist, spent July and August largely in the preparation of his report on the excavation and repair of the Casa Grande ruins, Arizona, during the preceding fiscal year, which was printed in the quarterly issue of the Smithsonian Miscellaneous Collections.

Doctor Fewkes was in the Southwest from October 24, 1907, to the end of the fiscal year. From November to the middle of March he was in charge of the excavation and repair work at Casa Grande, for which there was available the sum of $3,000, appropriated by Congress, to be expended under the direction of the Secretary of the Smithsonian Institution. The season's operations at Casa Grande began with excavations in Compound B, the second in size of the great compounds which form the Casa Grande group. This was found to be a rectangular area inclosed by a massive wall. Within this are many buildings, the majority of which were once used for ceremonial and communal purposes. On excavation it was ascertained that the two great pyramids in Compound B are terraced and that they contain seven distinct floors. The remains of small, fragile walled houses, resembling Pima jacales, were found upon the tops of these pyramids, and in the neighboring plazas subterranean rooms, with cemented floors and fireplaces, were unearthed under the massive walls. This compound was thoroughly repaired with Portland cement, and drains were built to carry off the surface water. A roof was built over the subterranean room, the decayed upright logs that once supported the walls were replaced with cedar posts, and other steps were taken for the permanent preservation of these interesting remains.

The walls of Compounds C and D were traced throughout; in the middle of the latter compound is a large building, the ground plan of which resembles Casa Grande. The most extensive structure excavated at Casa Grande is a clan house, a building 200 feet long, with 11 rooms whose massive walls inclose a plaza. In the middle of the central room of this cluster there is a seat, called by the Pima Indians "the seat of Montezuma." On the north side there is a burial chamber, the walls of which are decorated in several colors. This room contains a burial cyst in which was found the skeleton of a priest surrounded by ceremonial paraphernalia. The bases of the walls of the clan house were protected with cement, and drains were built to carry off water. For the convenience and information of visitors all the buildings excavated were appropriately labeled, and placards containing historical data were posted at various points. Although the appropriation was not sufficient for completing the work of excavation and repair of the Casa Grande group, the amount available made it possible to present a type ruin showing the general character of the ancient pueblo remains in the Gila and lower Salt River valleys.

At the close of the work at Casa Grande, Doctor Fewkes was able to make a comparative study of the mounds in the neighborhood of Phoenix, Mesa, and Tempe, and also of the ancient habitations on the Pima Reservation. Several large ruins in the vicinity of Tucson were visited, and an extensive ruin, known to the Pima and Papago as Shakayuma, was examined near the northwestern end of the Tucson Mountains. Several ancient reservoirs, now called "Indian tanks," situated east of Casa Grande, along the trail of the early Spanish discoverers, were identified by their historic names. In a reconnoissance down

San Pedro River to its junction with the Gila a number of ruins were discovered on both banks of the San Pedro and of Aravaipa Creek. A visit was also made to the imposing cliff houses, near Roosevelt dam, lately declared national monuments by executive proclamation. Ruins near the mouth of Tonto River were likewise examined.

At the close of April, by direction of the Secretary of the Smithsonian Institution, Doctor Fewkes proceeded to the Mesa Verde National Park in southern Colorado, where he took charge of the excavation and repair work of the celebrated Spruce-Tree House. This ruin was thoroughly excavated and its walls were repaired and put in good condition, in order that it might serve as a type ruin of the cliff dwellings of the Mesa Verde National Park. One hundred and fourteen rooms and eight kivas were excavated; two of the kivas were furnished with roofs reconstructed like aboriginal kiva roofs in Peabody House; an approach to the ruin was graded and drained, and labels were placed at convenient points for the information of visitors. Several large rooms, hitherto unknown, were unearthed, and the structure of the kivas was carefully studied. In order to deflect the water that fell on the ruin from the rim of the canyon, causing great damage, a channel 300 feet long was blasted out of the rock on top of the cliff. Two collections of considerable size were made, one at Casa Grande and the other at Spruce-Tree House. The former includes many rare and several unique objects that shed much light on our knowledge of the culture of the prehistoric inhabitants of the Casa Grande of the Gila; the latter includes skulls, pottery of rare forms and decoration, stone and wooden implements, basketry, cloth and other woven fabrics, sandals, and bone implements of various kinds. The objects from the Spruce-Tree House will be the first large accession by the National Museum of collections of objects from the Mesa Verde ruins. Doctor Fewkes completed his work at Spruce-Tree House on June 27.

Mr. J. N. B. Hewitt, ethnologist, remained in the office during the entire year. Much time was devoted to the collection and preparation of linguistic data for a sketch of Iroquoian grammar as exemplified by the Onondaga and the Mohawk, with illustrative examples from the Cayuga, Seneca, and Tuscarora dialects, for the forthcoming Handbook of American Indian Languages. In pursuing these studies Mr. Hewitt was fortunate in obtaining data which enabled him to supply translations of a number of very important archaic political and diplomatic terms in the native texts embodying the founding, constitution, and structure of the government of the League of the Iroquois. The meanings of these terms are now practically lost among those who speak the Iroquoian languages. As time permitted, these texts were studied and annotated for incorporation in a monograph on the above-mentioned phases of the government of the League of the Iroquois, a work which hitherto has not been seriously undertaken because of its cumbrousness, its extremely complicated character, and the great difficulty in recording the native material expressed in tens of thousands of words.

In addition to these studies Mr. Hewitt prepared for the Handbook of American Indians descriptions of the early mission towns and villages of the Iroquois tribes, brief biographical sketches of Red Jacket (Shagoyewatha) and Thayendanegea (Joseph Brant), and wrote several articles on Iroquois subjects.

From time to time Mr. Hewitt was called on to assist also in preparing data of an ethnologic nature for replies to correspondents of the office.

During the greater part of the year Dr. Cyrus Thomas, ethnologist, devoted attention chiefly to the preparation of the catalogue of books and papers relating to the Hawaiian Islands. After the number of titles had reached about

4,000 the Institution's committee on printing suggested some modification of the plan of the catalogue which necessitated a change in the form of the titles of periodicals—about one-third of the entire list. In connection with this work Doctor Thomas made supplementary examinations of works in the libraries of Washington, especially the Library of Congress and the libraries of the Department of Agriculture and the National Museum, and in those of Boston and Worcester. He carried on also, so far as time would permit, the preparation of subject cross-references.

Doctor Thomas continued to assist in the preparation of part 2 of the Handbook of American Indians, furnishing a number of articles, especially biographies, and assisting the editor in the reading of proofs, particularly with the view of detecting omissions, lack of uniformity in names, etc.

SPECIAL RESEARCHES.

In addition to the systematic investigations conducted by members of the bureau staff, researches of considerable importance were undertaken by collaborators of distinction. Dr. Franz Boas, honorary philologist of the bureau, practically completed his work on the Handbook of American Indian Languages, and at the close of the year a large part of the manuscript of volume 1 had been submitted to the bureau. This volume comprises an extended introduction by Doctor Boas, and a number of studies of selected languages, by special students, designed to illustrate the introductory discussion. With the approval of the Secretary the first of these studies—the Athapascan (Hupa)—by Dr. Pliny E. Goddard, was submitted to the Public Printer, with the view of having it placed in type for the use of Doctor Boas in preparing other sections for the press. The highly technical nature of the typesetting made this procedure necessary. Field work required in completing the handbook was limited to a brief visit by Doctor Boas to the Carlisle Indian School in Pennsylvania and to certain investigations among the remnant of the Tutelo tribe in Ontario, conducted by Mr. Leo J. F. Frachtenburg.

Dr. Herbert E. Bolton continued his studies relating to the tribes of Texas, so far as the limited time at his disposal permitted, but he was not able to submit the first installment of manuscript at the close of the year, as was expected. An outline of the work undertaken by Docton Bolton was presented in the last annual report.

During the year for the first time the study of native Indian music was seriously taken up by the bureau. Miss Frances Densmore was commissioned to conduct certain investigations relating to the musical features of the grand medicine ceremony of the Chippewa on the White Earth Reservation, Minn. The phonograph was employed in recording the songs, and after the close of the ceremony and visits to other Indian settlements Miss Densmore was called to Washington, where she reproduced her records and engaged successfully in recording songs of members of the various Indian delegations visiting the capital. A preliminary report was submitted by Miss Densmore, with the understanding that it is not to be printed until additional researches have been made in the same and related fields. The collection of phonographic records thus far obtained is extensive and the investigation promises results of exceptional interest and scientific value.

During the year arrangements were made to accept for publication as a bulletin of the bureau a report on certain explorations among the ancient mounds of Missouri by Mr. Gerard Fowke. These explorations were undertaken under the auspices of the Archæological Institute of America, but form an appropriate addition to the work of the bureau in this particular field. A

part of the collections made by the explorer was presented to the National Museum by the Archæological Institute.

It is proper that appreciation of the gratuitous labors of Dr. Nathaniel B. Emerson in editing and proof reading his memoir on the "Unwritten literature of Hawaii," accepted for publication during the year as Bulletin 38, and also the important part taken in the preparation of the "List of works relating to Hawaii," assigned to Bulletin 41, by Mr. Howard M. Ballou, should be acknowledged in this connection.

PRESERVATION OF ANTIQUITIES.

The bureau maintained its interest in the antiquities of the country during the year. Bulletin 35, The Antiquities of the Upper Gila and Salt River Valleys in Arizona and New Mexico, by Dr. Walter Hough, was issued. The $3,000 appropriated by Congress for the excavation, repair, and preservation of Casa Grande ruin in Arizona, and the $2,000 allotted by the Interior Department for similar work among the cliff dwellers of the Mesa Verde National Park in Colorado, were expended under the immediate auspices of the Smithsonian Institution, the execution of the work being intrusted to Dr. J. Walter Fewkes, ethnologist, as elsewhere reported.

Progress was made in the preparation of a catalogue of antiquities, and valuable data in this field were collected by Mr. W. B. Douglas, of the General Land Office, whose official labors recently brought him into contact with the antiquities of southeastern Utah.

During the year, by executive proclamation, several additions were made to the growing list of national monuments. Three of these are of especial archeological interest, namely, the Tonto National Monument, situated in the Tonto drainage basin, Gila County, Ariz., including two cliff dwellings not yet reported on in detail; the Gila Cliff Dwellings National Monument, in the Gila National Forest in New Mexico, comprising the group of cliff dwellings described in the bureau's Bulletin 35 (p. 30), and the Grand Canyon National Monument, comprising within its limits the Grand Canyon of the Colorado, in which are situated innumerable antiquities, including cliff dwellings, pueblos, dwelling sites, and burial places. The cliff dwellings are found mainly in the walls of the canyon, while the other remains are scattered along the margins of the plateaus.

COLLECTIONS.

The collections acquired during the year and transferred according to custom to the National Museum are not equal in importance to those of the preceding year. They comprise 14 accessions, the most noteworthy being collections of stone relics from the Potomac Valley, by G. Wylie Gill and W. H. Holmes; a collection of ethnologic material obtained from the Tahltan Indians of British Columbia, by Lieut. G. T. Emmons, U. S. Navy; a collection of stone implements from Washington State, by C. W. Wiegel; and relics and human bones from ancient burial places in Missouri, by Gerard Fowke.

PUBLICATIONS.

During the year progress was made on the Handbook of American Indians, and on the Handbook of American Indian Languages, as mentioned on other pages.

The edition of the twenty-fifth annual report, containing papers by Dr. J. Walter Fewkes on his explorations in the West Indies and in Mexico, was received from the Public Printer in September; Bulletin 30, the Handbook of American Indians, part 1, in March; Bulletin 33, Skeletal Remains Suggesting or Attributed to Early Man in America, in November; and Bulletin 35,

Antiquities of the Upper Gila and Salt River valleys in Arizona and New Mexico, in February. The twenty-sixth annual report was in the bindery at the close of the year. At that time Bulletin 34, Physiological and Medical Observations among the Indians of Southwestern United States and Northern Mexico, by Dr. Aleš Hrdlička, was for the main part in stereotype form, while Bulletin 38, Unwritten Literature of Hawaii, by Dr. Nathaniel B. Emerson, the manuscript of which was transmitted to the Public Printer early in the year, was largely in pages. The manuscript of Bulletin 39, Tlingit Texts and Myths, by Dr. John R. Swanton, and of a section of Bulletin 40, Handbook of the American Indian Languages, was also transmitted to the Public Printer.

The distribution of publications was continued as in former years. Fifteen hundred copies of the twenty-fifth annual report, and a like number of Bulletins 33 and 35, were distributed to the regular recipients, most of whom sent their own publications in exchange.

There was a greater demand for the publications of the bureau than during previous years. The great increase in the number of public libraries and the multiplication of demands from the public generally, resulted in the almost immediate exhaustion of the supply (3,500 copies) allotted to the bureau. During the year the bureau received from outside sources a number of the earlier issues of its reports and was thus able to respond to numerous requests from Members of Congress for complete sets, except the first annual report, the edition of which is entirely exhausted. About 1,000 copies of the twenty-fifth annual report, as well as numerous copies of the other annuals, bulletins, and separate papers, were distributed in response to special requests, presented largely through Members of Congress.

LINGUISTIC MANUSCRIPTS.

The archives of the bureau contain 1,659 manuscripts, mainly linguistic. The card catalogue of these manuscripts begun in the preceding year and completed during the year comprises more than 14,000 titles, which give as completely as possible the stock language, dialect, collector, and locality, as well as the character and the date, of the manuscript. While it was not possible in every instance to supply all the information called for under these heads, the catalogue is found to meet all ordinary requirements of reference. There were several important additions to the collection of manuscripts during the year, mainly through purchase. Prominent among linguistic students who have recently submitted the results of their labors to the bureau are Mr. Albert B. Reagan, who is making important investigations among the Hoh and the Quileute Indians of Washington, and Mr. J. P. Dunn, a leading authority on the Algonquian languages of the Middle West.

Owing to the number and bulk of the bureau's manuscripts, it is not possible to place them all in the fireproof vault, and about half the material is arranged in file cases, convenient of access. These manuscripts may be classified as: (1) dictionaries and vocabularies; (2) grammars, and (3) texts. By far the greater number are vocabularies, of varying length and completeness. Usually they give the Indian name and English equivalent without recording the derivation or current usage of the term given. Of greatest value are the several dictionaries, among them a Dhegiha (Siouan) dictionary prepared by the late Rev. J. Owen Dorsey, containing about 26,000 words; the Peoria dictionary of Dr. A. S. Gatschet; an Abnaki dictionary in three thick folio volumes, prepared by the Rev. Eugene Vetromile, by whom it was deposited with the bureau; and a dictionary, in five volumes, of the Choctaw tongue, by the Rev. Cyrus Byington.

ILLUSTRATIONS.

In the division of illustrations 2,810 photographic prints were made for use in illustrating publications, for correspondents, and for the cataloguing of negatives, which is now well in hand. A large number of prints of Indian subjects were acquired by purchase and filed for reference and for future use as illustrations. The photographic work included the making of 366 negatives, 310 of these being portraits of Indians of visiting delegations. The importance of the collection of portraits thus being brought together is indicated by the list of tribes represented, and is especially emphasized by the fact that these delegations usually consist of the best representatives of the tribes and hence may serve as types of the race. The negatives are 6½ by 8½ inches in size.

The tribes represented are as follows: Apache (Apache proper, Arizona and New Mexico; Chiricahua band held as prisoners in Oklahoma); Arapaho of northern Wyoming and southern Oklahoma; Cheyenne of northern Montana and southern Oklahoma; Chippewa (White Earth, Red Lake, and Mille Lac bands); Choctaw, Coeur d'Alène; Creek, Crow, Eskimo of Labrador; Flathead, Iowa, Kickapoo, Omaha, Osage, Oto, Pawnee, Pima, Potawatomi, San Blas (Argona tribe, Rio Diablo, south of Panama); Shoshoni, Sioux, Teton Sioux (including Brulé, Ogalala, Hunkpapa, and Sihasapa), and Yankton.

LIBRARY.

Good progress was made in accessioning and cataloguing the newly acquired books, pamphlets, and periodicals. In all there were received and recorded during the year 392 volumes, 800 pamphlets, and the current issues of upward of 500 serials, while about 600 volumes were bound at the Government Printing Office. The library now contains 14,022 volumes, 10,600 pamphlets, and several thousand numbers of periodicals relating to anthropology, most of which have been received by exchange. The purchase of books and periodicals has been restricted to such as relate to the bureau's researches.

Respectfully submitted.

W. H. Holmes, *Chief of Bureau.*

Dr. Charles D. Walcott,
Secretary of the Smithsonian Institution.

Appendix III.

REPORT ON THE INTERNATIONAL EXCHANGES.

Sir: I have the honor to submit the following report on the operations of the international exchange service during the fiscal year ending June 30, 1908:

In addition to carrying out the second term of the clause of the will establishing the Smithsonian Institution—"the diffusion of knowledge among men"—which was the occasion for the inauguration of this work in 1850, the ever-increasing usefulness of the system of international exchanges continues an important aid in the advancement of scientific knowledge throughout the world. Hundreds of thousands of works, containing, among other matters of importance, the details of the latest discoveries and inventions, are annually brought to this country, while a knowledge of everything of like nature originating here is, through this medium, disseminated abroad.

The growth of this system to its present comprehensive proportions has been made possible through the action of Congress and of our Government in negotiating treaties to place the exchange of government and scientific and literary publications upon a definite, legal, international footing. A resolution, approved March 2, 1867, provides that 50 copies of all documents printed by order of either House of Congress, and also that 50 copies of all publications issued by any department or bureau of the Government shall be placed at the disposition of the Joint Committee on the Library for exchange with foreign countries through the agency of the Smithsonian Institution. By a subsequent resolution, which was approved March 2, 1901, the number of sets of documents to be exchanged with foreign countries was increased to 100— the results of this governmental exchange through the Institution to inure to the benefit of the Library of Congress.

In addition to these two acts of the Congress of the United States, an important convention was signed at Brussels in 1886, which resulted for this country in a treaty for the international exchange of official documents and scientific and literary publications, ratified by the Senate and proclaimed by the President in 1889. Many nations not parties to this convention have since accepted its provisions and are conducting international exchange bureaus.

The appropriation by Congress for the service during the fiscal year ending June 30, 1908, was $32,200 (an increase of $3,400 over the preceding year), and the sum collected on account of repayments was $3,352.69, making the total available resources for international exchanges $35,552.69. Through this increase in the appropriation it was possible to inaugurate a system of work which has long been in mind—that of actively seeking returns from foreign countries for the exchanges sent to them by this Government and its departments and bureaus. Heretofore, although there has been some effort on the part of the Institution to secure proper returns, and the bureaus themselves have taken the matter up from time to time, the United States has been almost entirely dependent upon the good will of foreign establishments; but in February, 1908, an active and definite campaign was entered upon to secure reciprocal returns, the exchange bureau doing the work and bearing the expense. The result has already been more than satisfactory, but the effort is so recent that its full fruition could hardly be expected within the year. A number

of most gratifying acknowledgments have been received from various departments of the Government regarding this new work.

The transmission of packages has been much more prompt during the past twelve months than during any like period in the history of the service. The increased efficiency that this indicates is due in great measure to the practice inaugurated during the year of making shipments to all countries at least once a month. In carrying out this plan it has been necessary to expend considerably more for freight and postage than during previous years, but as the good results have been so obvious frequent shipments will continue to be made so long as the appropriations permit of the extra expense.

A communication was received during the year from the Russian Commission of International Exchanges, requesting, on behalf of the Library Commission of the Douma, that the United States Government enter into an exchange of parliamentary publications with Russia. The matter was taken up with the Librarian of Congress, and while it was considered that the exchange would be a most desirable one, in the absence of legislation setting apart a copy of the Congressional Record for this purpose permanent arrangements could not at once be made. The Librarian of Congress, however, succeeded in obtaining a copy of the Record for this purpose, and the interchange of parliamentary publications was entered into with Russia in March. As such information as the Congressional Record contains would be of more value if received without delay, sendings were made directly by mail, and this practice will be followed in the future.

It may be added in this connection that the French Chamber of Deputies has also made a request, through the Department of State, for the exchange of parliamentary documents, and that the matter was communicated to Congress by the department during the last session. No action was taken, however, though it is understood that the subject will be given consideration at a future date.

At the time the convention for the exchange of official documents and scientific and literary publications was entered into at Brussels, in 1886, an agreement was also made between the United States and several other countries for the immediate exchange of official journals, etc., but in the absence of the necessary legislation by Congress no steps have been taken by the Institution to carry this agreement into effect. As the subject has now been brought to the attention of Congress, a sufficient number of copies of the Congressional Record may be set aside for this purpose. I recommend, however, that the Smithsonian Institution seek to execute this agreement by legislation.

The Kingdom of Servia, which was one of the signatories to the Brussels convention of 1886, has never established a bureau of exchanges, and it has been necessary to forward transmissions to correspondents in that country through some other medium. Article I of the convention provides that each of the contracting States shall designate an office to take charge of the exchanges, and with a view to having such a bureau established in Servia the good offices of the Department of State have been solicited in bringing the matter to the attention of the Servian officials. While the number of publications at present exchanged between the United States and Servia is not large, it is hoped that if Servia will designate some office to take charge of the work it will result in a fuller interchange of publications between the two countries.

The arrangement of details concerning the shipment of a full set of government documents to China having finally been perfected, the first consignment, consisting of 16 cases, was, under date of February 20, 1908, forwarded to the American-Chinese publication exchange department of the Shanghai bureau of foreign affairs—the depository designated by the Government of China. It is most gratifying to the Institution that after so many years of almost constant endeavor on its part this interchange of documents has at last been effected.

As a result of correspondence between the Smithsonian Institution and the diplomatic envoys from the Republic of Liberia, regarding the establishment of a bureau of international exchanges in that country and the interchange of official documents between the Government of Liberia and the United States, the department of state at Mourovia has been designated to act as the exchange intermediary between the two countries, and the proposition to exchange official publications has been accepted by the envoys. A partial set of United States Government documents is being made up by the Library of Congress, and will be forwarded to Liberia as soon as received at the Institution.

Negotiations conducted through diplomatic channels have enabled the United States to enter into arrangements with the Government of Montenegro to exchange official documents, and the first sending of a partial set was made to that country during September, 1907. The documents are deposited in the ministère princier des affaires étrangères de Monténégro, Cetinje.

A service of international exchanges having been established under the direction of the Biblioteca Nacional at Santiago, Chile, the Chilean exchange agency has recently been transferred from the Universidad de Chile to that library. The Institution desires to record its grateful acknowledgment of the services rendered by the university during the past twelve years in the distribution of packages in Chile.

At the request of the Museo Nacional at San Salvador, consignments for distribution in that country will henceforth be sent in care of the ministerio de fomento at San Salvador.

The Institution has not yet been successful in prevailing upon an establishment in Korea to act as the exchange medium between that country and the United States. Transmissions to Korea, which were interrupted during the late Russo-Japanese war, have therefore not been resumed.

Through the wrecking of the steamship *Newark Castle* off the coast of southeast Africa, the Institution suffered the loss of several packages of exchanges destined for correspondents in Mauritius. So far as reported to this office, this is the only instance during the past year in which packages were lost while in transit. I am pleased to say that upon presenting the facts to the senders, duplicate copies of all the lost publications were furnished for transmission to Mauritius.

In continuation of the work inaugurated a few years ago, further steps have been taken to reduce to a minimum the danger in case of fire in the rooms occupied by the bureau. As a part of the plan of the Institution to divide the basement of the building into several fireproof sections, metal doors were placed in the exchange office and in the hall immediately adjoining. Several portable fire extinguishers have also been procured and placed where they may be most accessible in case of need.

INTERCHANGE OF PUBLICATIONS BETWEEN THE UNITED STATES AND OTHER COUNTRIES.

The total number of packages handled by the international exchange service during the past year was 203,098, an increase over the number for the preceding year of 13,268. The weight of these packages was 435,285 pounds, a decrease from 1907 of 34,251. This decrease in the weight is largely due to the reduction in the size of the government documents received for transmission. It may be added that this circumstance has resulted from the executive order issued January 20, 1906. This order, in brief, provides for the appointment by the heads of departments of advisory committees on printing and publication, whose duty shall be to see that unnecessary matter is excluded from reports and publications; to do away with the publication of unnecessary tables, and to require

that statistical matter be published in condensed and intelligible form; to prevent duplication of printing by different bureaus; to exclude unnecessary illustrations from department documents, etc.

The statement which follows shows in detail the number of packages exchanged between the United States and other countries:

Statement of packages received for transmission through the International Exchanges during the year ending June 30, 1908.

Country.	Packages.		Country.	Packages.	
	For.	From.		For.	From.
Abyssinia	1	.....	Gibraltar	13	1
Algeria	118	45	Gold Coast	5	.....
Angola	3	1	Grenada	6	.....
Antigua	36	.....	Great Britain and Ireland	20,562	8,666
Arabia	28	.....	Greece	1,295	.....
Argentina	3,044	1,531	Greenland	8	.....
Austria-Hungary	7,490	2,724	Guadeloupe	1	.....
Azores	22	.....	Guatemala	220	.....
Bahamas	46	.....	Haiti	1,011	.....
Barbados	92	.....	Hawaiian Islands	42	.....
Basutoland	4	.....	Honduras	214	.....
Beira	13	.....	Hongkong	114	.....
Belgium	4,184	2,604	Iceland	47	.....
Bermudas	38	.....	India	2,495	121
Bismarck Archipelago	1	.....	Italy	6,849	1,287
Bolivia	126	.....	Jamaica	220	.....
Borneo	7	.....	Japan	3,010	27
Brazil	2,337	676	Java	243	169
British America	6,604	704	Kongo Free State	1	.....
British Burma	9	.....	Korea	37	.....
British East Africa	1	.....	Lagos	1	.....
British Guiana	81	.....	Liberia	69	.....
British Honduras	60	.....	Lourenço Marquez	81	38
Bulgaria	166	14	Luxemburg	93	.....
Canary Islands	15	.....	Madagascar	25	.....
Cape Colony	1,469	75	Madeira	17	.....
Ceylon	199	1	Malta	89	.....
Chile	2,123	56	Martinique	14	.....
China	1,302	21	Mauritius	57	22
Colombia	1,192	.....	Mexico	1,781	513
Costa Rica	1,494	29	Montenegro	412	.....
Cuba	1,256	33	Montserrat	1	.....
Curaçao	13	.....	Morocco	3	.....
Cyprus	8	.....	Natal	191	2
Denmark	1,810	221	Netherlands	3,360	1,650
Dominica	18	.....	Nevis	10	.....
Dutch Guiana	26	.....	Newfoundland	131	123
Ecuador	178	.....	New South Wales	2,732	477
Egypt	404	303	New Zealand	1,620	446
Falkland Islands	15	.....	Nicaragua	207	1
Fiji Islands	25	.....	Norfolk Islands	13	.....
France	12,280	4,649	Norway	2,299	287
French Cochin China	31	.....	Orange River Colony	105	.....
German East Africa	8	.....	Panama	166	.....
Germany	23,501	8,285	Paraguay	143	100

Statement of packages received for transmission through the International Exchanges during the year ending June 30, 1908—Continued.

Country,	Packages.		Country.	Packages.	
	For.	From.		For.	From.
Persia	46	.....	Siam	208	.....
Peru	1,432	.....	Sierra Leone	23	.....
Philippine Islands	168	3	Society Islands	15	.....
Porto Rico	9	19	South Australia	1,469	80
Portugal	1,512	676	Spain	2,233	185
Portuguese West Africa	2	.....	Straits Settlements	189	1
Queensland	1,374	182	Sudan	27	2
Reunion	24	.....	Sumatra	2	.....
Rhodesia	35	.....	Sweden	7,852	221
Roumania	386	74	Switzerland	3,908	1,667
Russia	4,811	2,260	Tasmania	1,159	2
St. Croix	1	.....	Transvaal	1,240	6
St. Helena	15	.....	Trinidad	102	.....
St. Kitts	25	.....	Tunis	33	2
St. Lucia	4	.....	Turkey	1,378	.....
St. Martin	13	.....	Turks Islands	16	.....
St. Pierre and Miquelon	15	.....	United States	44,524	160,850
St. Thomas	15	.....	Uruguay	1,375	.....
St. Vincent	2	.....	Venezuela	1,131	.....
Salvador	168	.....	Victoria	2,827	510
Samoa	15	.....	Western Australia	1,270	449
Santo Domingo	19	6	Zanzibar	14	.....
Sarawak	3	.....	Total	203,098	203,098
Servia	89	1			

During the year there were sent abroad 1,909 boxes, of which 175 contained complete sets of United States Government documents for authorized depositories, and 1,734 were filled with departmental and other publications for depositories of partial sets and for distrbution to miscellaneous correspondents.

EXCHANGE OF GOVERNMENT DOCUMENTS.

The number of packages sent abroad through the international exchange service by United States Government institutions during the year was 102,694, an increase over those forwarded during the preceding twelve months of 2,580; the number received in exchange was 16,853, an increase of 5,212. It is gratifying to note that the increase in the number of packages received is greater than the increase in the number sent out. This is due in large measure to the special efforts made by the institution during the past year to obtain for the Library of Congress and the several government departments and bureaus more adequate returns for the publications sent to their foreign correspondents, to which reference has previously been made. From the returns that have thus far been received in response to the requests of the institution, I feel confident that the exchanges from abroad will, during the coming year, be even greater than during the past twelve months.

FOREIGN DEPOSITORIES OF UNITED STATES GOVERNMENT DOCUMENTS.

In accordance with treaty stipulations and under the authority of the congressional resolutions of March 2, 1867, and March 2, 1901, setting apart a certain number of documents for exchange with foreign countries, there are now

sent regularly to depositories abroad 54 full sets of United States official publications and 32 partial sets, China having been added during the year to the list of countries receiving full sets and Montenegro and Liberia to the list of those receiving partial sets, the details concerning which have been given elsewhere in this report. A list of the recipients of full and partial sets was given in the report for last year and need not be repeated here.

CORRESPONDENTS.

The record of exchange correspondents at the close of the year contained 60,123 addresses, being an increase of 2,016 over the preceding year. A table showing the number of correspondents in each country was given in the last report.

LIST OF BUREAUS OR AGENCIES THROUGH WHICH EXCHANGES ARE TRANSMITTED.

Following is a list of bureaus or agencies abroad through which the distribution of exchanges is effected. Those in the larger and many in the smaller countries forward to the Smithsonian Institution in return contributions for distribution in the United States.

Algeria, via France.
Angola, via Portugal.
Argentina: Sección de Depósito, Reparto y Canje de Publicaciones, Biblioteca Nacional, Buenos Aires.
Austria: K. K. Statistische Central-Commission, Vienna.
Azores, via Portugal.
Barbados: Imperial Department of Agriculture, Bridgetown.
Belgium: Service Belge des Échanges Internationaux, Brussels.
Bermuda. (Sent by mail.)
Bolivia: Oficina Nacional de Inmigración, Estadística y Propaganda Geográfica, La Paz.
Brazil: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Rio de Janeiro.
British Colonies: Crown Agents for the Colonies, London.[a]
British Guiana: Royal Agricultural and Commercial Society, Bridgetown.
British Honduras: Colonial Secretary, Belize.
Bulgaria: Institutions et Bibliothèque Scientifiques de S. A. R. le Prince de Bulgarie, Sofia.
Canada. (Sent by mail.)
Canary Islands, via Spain.
Cape Colony: Government Stationery Department, Cape Town.
Chile: Servicio de Canjes Internacionales, Biblioteca Nacional, Santiago.
China: Zi-ka-wei Observatory, Shanghai.
Colombia: Oficina de Canjes Internacionales y Reparto, Biblioteca Nacional, Bogota.
Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.
Cuba. (Sent by mail.)
Denmark: Kongelige Danske Videnskabernes Selskab, Copenhagen.
Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.
Ecuador: Ministerio de Relaciones Exteriores, Quito.
Egypt: Director-General, Survey Department, Cairo.
France: Service Français des Échanges Internationaux, Paris.
Friendly Islands. (Sent by mail.)

[a] This method is employed for communicating with several of the British colonies with which no medium is available for forwarding exchanges direct.

Germany: Karl W. Hiersemann, Königsstrasse 3, Leipzig.
Great Britain and Ireland: Messrs. William Wesley & Son, 28 Essex street, Strand, London.
Greece: Bibliothèque Nationale, Athens.
Greenland, via Denmark.
Guadeloupe, via France.
Guatemala: Instituto Nacional de Guatemala, Guatemala.
Guinea, via Portugal.
Haiti: Secrétaire d'Etat des Relations Extérieures, Port au Prince.
Honduras: Biblioteca Nacional, Tegucigalpa.
Hungary: Dr. Julius Pikler, Municipal Office of Statistics, City Hall, Budapest.
Iceland, via Denmark.
India: India Store Department, India Office, London.
Italy: Ufficio degli Scambi Internazionali, Biblioteca Nazionale Vittorio Emanuele, Rome.
Jamaica: Institute of Jamaica, Kingston.
Japan: Department of Foreign Affairs, Tokyo.
Java, via Netherlands.
Korea. (Shipments temporarily suspended.)
Liberia: Department of State, Monrovia.
Lourenço Marquez: Government Library, Lourenço Marquez.
Luxemburg, via Germany.
Madagascar, via France.
Madeira, via Portugal.
Mexico. (Sent by mail.)
Mozambique, via Portugal.
Natal: Agent-General for Natal, London.
Netherlands: Bureau Scientifique Central Néerlandais, Bibliothèque de l'Université, Leyden.
Newfoundland. (Sent by mail.)
New Guinea, via Netherlands.
New Hebrides. (Sent by mail.)
New South Wales: Board for International Exchanges, Public Library, Sydney.
New Zealand: Dominion Museum, Wellington.
Nicaragua: Ministerio de Relaciones Exteriores, Managua.
Norway: Kongelige Norske Frederiks Universitet Bibliotheket, Christiania.
Paraguay: Ministerio de Relaciones Exteriores, Asuncion.
Persia: Board of Foreign Missions of the Presbyterian Church, New York City.
Peru: Oficina de Reparto, Depósito y Canje Internacional de Publicaciones, Ministerio de Fomento, Lima.
Portugal: Serviço de Permutações Internacionaes, Bibliotheca Nacional, Lisbon.
Queensland: Board of Exchanges, Brisbane.
Roumania, via Germany.
Russia: Commission Russe des Echanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
Saint Christopher. (Sent by mail.)
Salvador: Ministerio de Relaciones Exteriores.
Santo Domingo. (Sent by mail.)
Servia, via Germany.
Siam: Minister for Foreign Affairs, Bangkok.
South Australia: Public Library of South Australia, Adelaide.
Spain: Depósito de Libros, Cambio Internacional y Biblioteca General del Ministerio de Instrucción Pública y Bellas Artes, Madrid.
Sumatra, via Netherlands.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.

Switzerland: Service des Echanges Internationaux, Bibliothèque Fédérale Centrale, Bern.
Syria: Board of Foreign Missions of the Presbyterian Church, New York.
Tasmania: Royal Society of Tasmania, Hobart.
Transvaal: Government Library, Pretoria.
Trinidad: Victoria Institute, Port of Spain.
Tunis, via France.
Turkey: American Board of Commissioners for Foreign Missions, Boston.
Uruguay: Oficina de Depósito, Reparto y Canje Internacional, Montevideo.
Venezuela: Biblioteca Nacional, Caracas.
Victoria: Public Library of Victoria, Melbourne.
Western Australia: Public Library of Western Australia, Perth.
Zanzibar. (Sent by mail.)

RULES GOVERNING TRANSMISSION OF EXCHANGES.

The rules governing the transmission of exchanges have been slightly modified during the year, and under date of February 1, 1908, a new edition was published, which is here reproduced for the information of those who may wish to make use of the facilities of the service in the forwarding of exchanges:

In effecting the distribution of its first publications abroad, the Smithsonian Institution established relations with certain foreign scientific societies and libraries, by means of which it was enabled to assist materially institutions and individuals of this country in the transmission of their publications abroad, and also foreign societies and individuals in distributing their publications in the United States.

In recent years the Smithsonian Institution has been recognized by the United States Government as in charge of its official exchange bureau, through which the publications authorized by Congress are exchanged for those of other governments; and by a formal treaty it acts as intermediary between the learned bodies and literary and scientific societies of the contracting states for the reception and transmission of their publications.

Attention is called to the fact that this is not a domestic, but an international exchange service, and is used to facilitate exchanges, not within the United States, but between the United States and other countries only. As exchanges from domestic sources for addresses in Hawaii, the Philippine Islands, Porto Rico, and other territory subject to the jurisdiction of the United States do not come within the designation "international," they are not accepted for transmission.

Packages prepared in accordance with the rules enumerated below will be received by the Smithsonian Institution from persons or institutions of learning in the United States and forwarded to their destinations through its own agents, or through the various exchange bureaus in other countries. The Smithsonian agents and these bureaus will likewise receive from correspondents in their countries such publications for addresses in the United States and territories subject to its jurisdiction as may be delivered to them under rules similar to those prescribed herein, and will forward them to Washington, after which the Institution will undertake their distribution.

On the receipt of a consignment from a domestic source it is assigned a "record number," this number being placed on each package contained in the consignment. A record is then made of the entire list of packages under the sender's name, and the separate packages are entered under the name of the person or office addressed. An account is thus established with every correspondent of the Institution, which shows readily what packages each one has sent or received through the exchange service. The books are then packed in boxes with contributions from other senders for the same country, and are for-

warded by fast freight to the bureau or agency abroad which has undertaken to distribute exchanges in that country. To Great Britain and Germany, where paid agencies of the Institution are maintained, shipments are made weekly; to all other countries transmissions are made at intervals not exceeding one month.

Transmissions from abroad for correspondents in the United States and territory subject to its jurisdiction are distributed under frank by registered mail, a record first having been made of the name of the sender and of the address of each package.

The Smithsonian Institution assumes no responsibility in the transmission of packages, but at all times uses its best endeavors to forward promptly to destination exchanges entrusted to its care.

The rules governing the Smithsonian International Exchange Service are as follows:

1. Packages intended for transmission through the Institution should be addressed "Smithsonian Institution, International Exchange Service."

2. The Institution and its agents will not knowingly receive for any address purchased books; apparatus or instruments of any description, whether purchased or presented; nor specimens of any nature except when special permission from the Institution has been obtained, and then only under the following conditions:

(*a*) Specimens in fluid will not be accepted for transmission.

(*b*) Botanical specimens will be transmitted at the rate of 8 cents per pound.

(*c*) All other specimens will be transmitted at the rate of 5 cents per pound.

3. In forwarding exchanges the sender should address a letter to the Institution, stating by what route the consignment is being shipped to Washington, and the number of boxes or parcels of which it is composed.

4. Packages should be legibly addressed, using the language of the country for which they are intended when practicable, and avoiding all abbreviations. When packages are intended for societies and other establishments, names of individuals should be omitted from labels in order to avoid any possible dispute as to ownership.

5. Packages should be securely wrapped in stout paper and, when necessary, tied with strong twine.

6. No package to a single address should exceed one-half of 1 cubic foot.

7. Letters or other written matter are not permitted in exchange packages.

8. Exchanges must be delivered to the Smithsonian Institution or its agents with all charges paid.

9. If donors desire acknowledgements, each package should contain a blank receipt to be signed and returned by the establishment or individual addressed; and if publications are desired in exchange, the fact should be stated on the card or package.

In conclusion, mention should be made of the valuable services which are rendered the Institution by those correspondents abroad who give their personal attention and doubtless often expend private means in furthering the interests of the international exchange service. The thanks of the Smithsonian Institution are also due Mr. Charles A. King, deputy collector of customs at the port of New York, for his constant assistance in clearing exchange consignments from abroad.

Respectfully submitted.

CYRUS ADLER,
Assistant Secretary, in charge of Library and Exchanges.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix IV.

REPORT ON THE NATIONAL ZOOLOGICAL PARK.

Sir: I have the honor to submit the following report on the operations of the National Zoological Park for the fiscal year ending June 30, 1908:

ROADS AND WALKS.

The most significant advance made in the park during the year has been the decided improvement in the means of access which was effected by means of a special appropriation of $15,000 made by Congress for the reconstruction and repairing of walks and roadways.

From this appropriation there were put in excellent condition the roadways from the concrete bridge near the Quarry Road entrance and from the same point to the ford near the Klingle road. A concrete walk was constructed from the bridge to near the lion house, and a new permanent footway was begun to replace the temporary wooden walk by which most visitors entering from the Adams Mill road reach the animal houses. A steam roller was found to be necessary for this work and also for general use in the park. An attempt was made to hire one, but finding this impracticable, one was purchased, weighing between 7 and 8 tons, at a cost of $2,230, and has proved an excellent investment.

When the roadbed was broken up it was found throughout a large part of the extent to be in much worse condition than expected. The original macadam pavement was in some places almost wholly gone, while in the creek valley the roadbed had settled into the soft ground. Practically the entire body of macadam had to be supplied. Potomac gneiss was used for the base and in part for the middle layer. Limestone was used for the top layer and for a considerable portion of the middle layer. The work was delayed very much because of a difficulty in securing deliveries of stone. The large amount of new construction and repair work that was going on upon the city streets made such a demand for teams that contractors who supplied the stone for the work in the park were unable to obtain them to do the hauling. The expense of putting these roads in proper order was therefore greater than had been anticipated. The total sum expended, including the laying of gutters, was $10,300.

The macadam walk extending from the Quarry-road entrance to the concourse, which was in extremely bad condition, was replaced by a concrete walk. The length of this walk was 1,100 feet, with a width of 10 feet throughout most of the distance and of 12 feet from the entrance to the concrete bridge. The cost of this walk was $1.32½ per square yard, and the total was $1,936.46.

The walk from the Adams Mill road entrance to the bowlder footbridge to take the place of the wooden walk is 560 feet in length, with an average width of 9 feet. From the bowlder footbridge to the upper end of the walk the rise is 102 feet. The difficulties of making this walk were considerable, for in some parts of its course it was necessary to cut into the face of a steep hillside. Great pains were taken to shape the bared surfaces and to plant them with indigenous ferns and other plants, so as to present a natural appearance.

It is believed that this work was unusually successful. This walk was not entirely completed at the close of the year, but will soon be finished. The total cost will be about $2,000, of which $1,350 was expended during the year.

A concrete walk along the front and west side of the small mammal house, for which a contract was made under the previous year's appropriation, was completed soon after the beginning of the year. This walk was extended to the temporary bird house.

BUILDINGS AND INCLOSURES.

The outdoor cages on the west side of the small mammal house were completed and are now in use. The floors of these cages have a base of stone, set after the manner of Telford pavement, with from 2 to 3 inches of earth over it. The fronts and top are constructed of three-eighths-inch round steel, and the partitions are of wire netting with three-quarter-inch square mesh. This netting is double, with a space of 4 inches between the two, so that animals in adjoining cages can not injure one another.

The two additional bear yards built from the previous year's appropriation were completed early in this year, and occupied. A concrete walk 12 feet wide was constructed in front of these and of the two yards previously built. Two more yards, work on which was begun in April, have been constructed mainly from this year's appropriation. It is expected that the four yards required to complete the entire series of ten will be completed during the year 1908–9.

Work was begun on inclosures for pheasants and other game birds, and this will be completed early in the coming year.

A considerable amount of repair work has been necessary on buildings and inclosures during the current year. The west wall of the antelope house and a portion of the north end had to be rebuilt. Owing to lack of sufficient funds for better construction, this building was originally constructed in the cheapest materials, and the west wall was so much decayed that it was weak and unsafe. Several other parts of the building had been repaired in previous years. The roof of the temporary portion of the lion house was leaking badly and had to be repaired and the skylights thoroughly overhauled and repaired. The roof of the temporary bird house was also repaired. The fence of the inclosures about the llama house was entirely rebuilt. The buffalo fence also required repair and a considerable amount of new fencing, and considerable repair work had to be done on various other wire fences.

The building occupied as an aquarium is rapidly reaching a state when it must either be entirely rebuilt or wholly demolished. It will be remembered that it was originally a hay shed built in the most temporary manner out of Virginia pine lumber, and that constant repairs have been required to keep it in a condition for occupancy. The foundations on which the tanks rest are sinking and several of the larger plate-glass fronts have been cracked so that they can not be used.

The gates at Adams Mill road and Quarry road entrances which had been taken down in order to make way for changes in the street approaches, were replaced and arrangements made to close the park at 9 p. m.

A considerable amount of planting was done during the year, the area about the small mammal house and extending toward the lion house was brought to the final grade, covered with soil, and planted. The banks near the flying cage were also planted, and shade trees and shrubs were set in various other places. Nut-bearing trees and bushes were also planted to furnish food for squirrels.

Plans for a hospital and laboratory building were prepared during the year, but construction of the building was deferred, as all available funds were needed for other purposes.

VISIT OF THE INTERNATIONAL ZOOLOGICAL CONGRESS.

A very noteworthy event of the year was the visit made to the park by members of the International Zoological Congress, which occurred on September 4, 1907, after the general meeting of the congress held at Boston on August 15 to 24.

Arrangements were made by a local committee for their entertainment while in this city, so that the park was at no expense. About 80 of the foreign visitors came to the park and spent nearly the whole day inspecting the collection. A luncheon was served them on the stretch of lawn extending along the bank of the creek just above the lower bridge. They appeared to be much impressed by the installation and appearance of the animals. Among the visitors were three directors of foreign zoological gardens, viz, Messrs. J. Büttikofer, of Rotterdam; W. H. D. Le Souef, of Melbourne, and R. F. Scharff, of Dublin. M. G. Loisel, commissioned by the French Government to inspect foreign zoological establishments, was also present.

ACCESSIONS AND LOSSES.

Gifts included a great anteater and two curassows, from Hon. H. G. Squiers, American minister to Panama.

A fine mule deer buck, from James A. Carroll, superintendent, Indian School at Mescalero, N. Mex.

A collection of 25 animals was received as an exchange from the Municipal Zoological Garden at Buenos Aires, Argentine Republic. This included a pair of alpacas, one llama, a pair of grisons, a pair of viscachas, a pair of Patagonian cavies, a pair of common rheas, a Patagonian rhea, a Maguari stork, and other mammals and birds.

Purchases.—The purchases included a male tiger from the Malay Peninsula, as a mate for the female previously obtained from the same region, three Alaskan brown bears, an orang, a pair of wanderoo monkeys, a pair of Kongo harnessed antelopes, a gnu, a male nilgai as a mate for the female already in the collection, a pair of guanacos, five American otters, a secretary vulture, etc.

Births.—The births numbered 91 and included a Brazilian tapir, a yak, a Barbary sheep, a Kongo harnessed antelope, deer of several species, a viscacha, kangaroos, wolves, etc. Eleven wild turkeys were hatched, and various herons and other birds nested in the flying cage.

Deaths.—The deaths included the lion Lobengula, presented by Mr. H. C. Moore in 1894, which died from chronic interstitial pneumonia; a young Steller's sea lion and a young Alaskan brown bear, lost from pneumonia; a black leopard from cirrhosis of the liver; and a great anteater from hemorrhagic nephritis. An infection with a bacillus resembling that of hog cholera took off 12 pigeons of various species. An outbreak of serious gastro-enteritis among the cats, supposed to have been due to the meat used, resulted in 2 deaths; 5 animals were affected.

One hundred and seventeen autopsies were made by the pathologists of the Bureau of Animal Industry and gave the following results:

Gastritis and enteritis, 26; hemorrhagic proctitis, 1; pseudo-membranous colitis, 1; impaction of rectum, 1; impaction of rumen, 1; peritonitis with intestinal obstruction, 1; peritonitis with hernia of large intestine, 1; ascaris and trematode infestation, 1; tuberculosis, 18; pneumonia, 13; congestion of lungs, 4; porocephalus infestation of lungs, 1; bacillus enteritidis, 12; proteus vulgaris, 2; nephritis, 8; cirrhosis of liver, 1; fatty degeneration of liver, 1; pericarditis, 2; dilation of heart, 1; hyaline degeneration of heart muscle, 1;

internal hemorrhage from rupture of hematoma on gizzard, 1; hemistomiosis, 1; pyemia, 1; rabies, 2; carcinoma of uterus, 1; carcinoma of liver, 1; psoric marasmus, 1; ruptured oviduct, 1; starvation (young coyotes), 4; congestion of brain (from accident), 1; gunshot wound (puma killed because of curvature of spine), 1; cause of death not found, 3; total, 117.

VISITORS.

The number of visitors to the park during the year was 652,500, a daily average of about 1,783. The largest number in any month was 109,240, in April, 1908—a daily average of 3,524.

During the year there visited the park 170 schools, Sunday schools, classes, etc., with 4,638 pupils, a monthly average of 386 pupils. While most of them were from the city and immediate vicinity, 29 of the schools were from neighboring States; and classes came from Fairhaven, Fitchburg, Lexington, Waltham, and Boston, Mass.

NEEDS OF THE PARK.

General aviary.—The temporary bird house is crowded during the winter far beyond its proper capacity, and it is impossible to care for the birds satisfactorily. When it was built, and also at the time that additions were made, the funds available for the purpose were so small that it was necessary to build in the cheapest manner possible, so that the house has already required considerable repair, and will very soon have to be largely rebuilt. The park has a good collection of birds, including a number of rare, interesting, and valuable specimens, sufficient to fill at once a large aviary and make one of the most important and attractive features of the park.

Antelope house.—The temporary building used for this purpose is quite inadequate, and, while it has served the purpose fairly well for the temporary housing of a few of these animals, it is far from satisfactory for long-continued use.

Inclosures.—Inclosures, with pools, for sea lions and seals. The park now has on exhibition both the common California sea lion and the great northern or Steller's sea lion, also seals, but these animals now have only very small pools, which were intended for other animals, and which are not large enough to allow the activity which they need in order to keep in health and vigor.

Office building near the center of the activities of the park.

Public comfort places.—The present structures are unsightly in appearance, inadequate, and becoming seriously in need of repair.

Restaurant.—There is now in use as a restaurant merely an inclosed platform with roof and a small inclosed shed attached for cooking purposes, and no place where visitors can take lunch with comfort, especially in cold weather.

Shelters for visitors are needed in various parts of the park.

The little hill, occupied by the condor cage and various small shelters, is very unsatisfactory in appearance and arrangement, and should be rearranged or cleared for something more suitable for so prominent a location.

The roads, which it was not possible to reconstruct from the special appropriation, are coming to be in very bad condition, and are seriously in need of thorough repair. This should include paving the ford across the creek in the line of the driveway which leads out to Cathedral avenue, and should also include the extension of the guard wall at the side of the Adams Mill road along the entire extent of the steep bank. Much of the macadam walk is in very unsatisfactory condition and needs thorough repair, and a concrete walk should be built about the flying cage.

STATEMENT OF THE COLLECTION.

Accessions during the year:

Presented	68
Received in exchange	32
Purchased	397
Deposited	2
Born and hatched in National Zoological Park	91
Captured in National Zoological Park	1
Total	591

Presented.

White-throated capuchin, Lieut. H. F. D. Long, U. S. Marine Corps	1
Brown capuchin, E. B. McLean	1
Ocelot, donor unknown, Trinidad, West Indies	1
Red fox, E. P. Brown, Washington, D. C	1
Red fox, H. A. Finley & Son, Washington, D. C	1
Common ferret, E. L. Barclay, Washington, D. C	2
American badger, the President	1
Mule deer, James A. Carroll, Mescalero, N. Mex	1
Angora goat, No. 8 Fire Engine Company, Washington, D. C	1
Common goat, R. C. Adams, Washington, D. C	1
Gray squirrel, the President	6
Great ant-eater, Hon. H. G. Squires, minister to Panama	1
Opossum, the President	4
Opossum, Lee H. Smith, Washington, D. C	1
Opossum, Mrs. W. T. Lockwood, Washington, D. C	1
Double yellow-headed Amazon, Miss N. Morrison, Washington, D. C	1
Porto Rican parrot, August Busck, United States Department of Agriculture	1
Parrakeet, August Busck, United States Department of Agriculture	2
Parrakeet, Mrs. A. Adee, Washington, D. C	2
Parrakeet, J. C. O'Loughlin, Washington, D. C	2
Red-tailed hawk, donor unknown, Washington, D. C	1
Great horned owl, Mr. Lee, Washington, D. C	1
Barred owl, Curtis Porter, Washington, D. C	1
Barred owl, J. E. Woodwell, Washington, D. C	1
Barn owl, janitor of Alabama Apartment House, Washington, D. C	2
Screech owl, Mrs. Miller, Washington, D. C	1
Screech owl, R. Edmonston, Washington, D. C	1
Curassow, Hon. H. G. Squires, minister to Panama	1
Guan, Hon. H. G. Squires, minister to Panama	1
White-winged dove, Lieut. Paul D. Bunker, U. S. Army, Key West Barracks, Fla	1
Ringdove, Dr. J. R. Spangler, York, Pa	1
Ringdove, Miss E. C. Day, Washington, D. C	2
Siskin, Mrs. Ellis Spear, Washington, D. C	1
Java sparrow, Miss Weil, Washington, D. C	1
Whistling swan, Frank P. Hall, Washington, D. C	1
Black-crowned night heron, J. N. Ruffin, New York City	1
Alligator, W. L. Harris, Charleston, S. C	3
Alligator, Mrs. J. M. Holton, Washington, D. C	1
Alligator, Georgetown Hospital, Washington, D. C	1

Banded rattlesnake, Smyth Brothers, Renovo, Pa 1
Mohave snake, J. Belcore, Imperial, Cal 2
Hog-nosed snake, R. C. Ambler, Home, W. Va 1
Chicken snake, Armadillo Curio Company, Boerne, Tex 2
Garter snake, Armadillo Curio Company, Boerne, Tex 4
Garter snake, Armadillo Curio Company, Boerne, Tex 1
Green snake, Armadillo Curio Company, Boerne, Tex 1
Mouse snake, Armadillo Curio Company, Boerne, Tex 1

Summary:

Animals on hand July 1, 1907	1,193
Accessions during the year	591
Total	1,784
Deduct loss (by exchange, death, and returning of animals)	382
On hand June 30, 1908	1,402

	Species.	Individuals.
Mammals	146	565
Birds	168	713
Reptiles	36	124
Total	350	1,402

Respectfully submitted.

FRANK BAKER, *Superintendent.*

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix V.

REPORT ON THE ASTROPHYSICAL OBSERVATORY.

Sir: During the past fiscal year there have been no alterations of the observatory buildings beyond slight necessary repairs. Some apparatus for research has been purchased, the usual scientific periodicals have been continued, and a few books of reference have been added to the library.

The personnel has remained practically unchanged. Miss M. L. Scott served as additional computer from July 5 to August 10, 1907. Mr. J. C. Dwyer, who had served faithfully and with fast growing general usefulness as messenger for several years, died on January 25, 1908. Mr. Meyer Segal was employed as messenger, beginning February 19, 1908, and Mr. L. B. Aldrich as bolometric assistant from May 11, 1908, to the end of the fiscal year.

The work of the observatory may be considered under the following heads: 1. Publications; 2. Washington observations; 3. Solar eclipse expedition; 4. Mount Wilson observations.

1. PUBLICATIONS.

As stated in last year's report, the preparation of Volume II of the annals had been nearly finished before the beginning of the fiscal year. But the completion of the computations, and the revising and rechecking of results continued to occupy the staff until the latter part of October. The revision of proofs continued intermittently until March, and the edition of 1,500 copies was received in April. About 1,300 copies were at once distributed to libraries, observatories, scientific periodicals, and men of science throughout the world. Commendatory notices by letter and in journals, and requests for copies of the work have been numerous.

2. WASHINGTON OBSERVATIONS.

The observation of the relative brightness of different parts of the sun's disc has gone forward as there was opportunity. Improved methods of observing and reducing these observations have been adopted.

Preparations for observing the absorption of water vapor in long columns of air, for the region of the spectrum where rays are chiefly emitted by the earth, have been carried to such a state that preliminary measurements have been made. Many difficulties attend this research, for the rays observed are wholly invisible to the eye, and are very feeble, even in the emission of the hottest bodies. In sun's rays they are almost wholly absent, because of the absorbing action of the water vapor encountered by the sun's rays in our atmosphere. Few substances are transparent to them, and even rock salt fails in transparency, for some rays are of very long wave-length, which are of considerable importance in the spectrum of the earth. Stray radiation from the walls of the room must be taken into account, and the straying of rays of less wave-length from regions of the spectrum where the emission of hot sources is plentiful is a troublesome difficulty. The investigation is being carried on with a column of moist air about 400 feet in length. The work is under Mr. Fowle's direction.

3. SOLAR ECLIPSE EXPEDITION—A BOLOMETRIC STUDY OF THE SOLAR CORONA.

The Smithsonian Institution was represented among observers of the eclipse of January 3, 1908, by a small expedition including the writer and Mr. A. F. Moore, of Los Angeles. Our charges were defrayed by the Institution, but we went by invitation and with the cooperation of Director Campbell, of the Lick Observatory, and shared in the benefits of the careful provision which he made for the general welfare and success. The observations were made at Flint Island in the South Pacific Ocean. My absence from Washington extended from November 5, 1907, to February 2, 1908.

We proposed to measure, with that extremely sensitive electrical thermometer called the "bolometer," the intensity of the radiation of the solar corona, and to determine the quality of coronal light as compared with sunlight.

In the year 1900 the first bolometric observations of the corona were made by Smithsonian observers. From these observations it was inferred that, as regards quality, the radiation of the inner corona was far richer than that reflected from the moon in visible light. In view of this consideration and others, the inferences drawn by the writer from the bolometric study of the corona made in 1900 were unfavorable to the view that the radiation of the inner corona is produced mainly by the incandescence of matter heated to high temperatures by reason of its proximity to the sun. The bolometric observations at Flint Island were designed to test the inferences above referred to and to measure more definitely the quantity and quality of the coronal radiation.

Apparatus.—A concave mirror of 50 centimeters diameter and only 100 centimeters focus, mounted equatorially and driven by a clock, served to produce a very intense image of the corona. A small guiding telescope was attached to the mirror frame so that the observer might point toward any desired object. In the focus of the mirror was placed the bolometer. A glass plate 3 millimeters thick was fixed close to the bolometer, between it and the mirror, so that the radiation examined was thereby limited to wave-lengths less than about 3μ. About 10 centimeters in front of the bolometer was a blackened metal shutter, which cut off the beam except when designedly opened. The opening of this shutter, therefore, exposed the central part of the bolometer to such rays as are transmissible by glass. Between the shutter and the glass plate, and close to the latter, was a special screen composed of a thin stratum of asphaltum varnish laid on one side of a plane parallel glass plate 3 millimeters thick. This screen was held out of the beam by a spring, except when designedly interposed. Its property, when used, was to cut off nearly all the visible part of the radiation, while transmitting nearly all of the infra-red rays transmissible by glass. By interposing this absorbing screen the proportion of the observed radiation which lay in the infra-red spectrum could be roughly determined.

The equatorial was set up at Flint Island on the beach at about 12 meters distance from the galvanometer used for observing the indications of the bolometer. Two galvanometers were provided, exactly alike in resistance and general construction, and arranged so that if at the last moment any accident should happen to one the observer might pass at once to the other.[a] A thatched hut, shaded by palm trees, sheltered the galvanometers and their appliances, and was found to give most satisfactory protection both from heat and rain. During the eclipse a rise of temperature of one bolometer strip of about $0^{\circ}.000{,}01$ C. would have produced 1 millimeter deflection of the galvanometer. It is possible to detect temperature changes of $0^{\circ}.000{,}000{,}01$ C. with the bolometer, under special conditions, but the sensitiveness employed was regarded as good for a temporary installation.

[a] This prudent measure was suggested by Mrs. Abbot.

The observations.—The approach of totality was uncommonly exciting on this occasion. Early in the morning the sky was overcast with thin high clouds, but these gradually grew thinner, so that after 9 a. m. the prospects indicated a streaky sky, containing something almost too thick for haze, but almost too thin for cirrus clouds. These prospects were fulfilled exactly during totality, but in the quarter of an hour next preceding a thick cloud came up, rain fell fast from 11 h. 8 m. to 11 h. 14 m., and the sky became clear of the low cloud only fifteen seconds before totality at the Smithsonian station. The rapid change from fair prospects to completely discouraging ones, and the return to good conditions just at the critical time, will long be remembered. Our entire immunity from rain during totality was due to the fact that our station was about 1,000 feet north of the one occupied by the Lick Observatory.

The intensity and quality of sunlight was determined within twenty-five minutes of totality, both before and after, and during totality measurements were made at five different regions of the corona and on the dark moon. A general summary of the results of these and other observations follows:

Intensity of rays (observed through glass).

Source.	Intensity for unit angular area.
Sun near zenith, Flint Island	10,000,000
Sky 20° from sun, Flint Island	140
Sky far from sun, Flint Island	31
Sky average, Flint Island	62
Sky average, Mount Wilson, Cal	15
Moon at night, Flint Island	12(?)
Moon during eclipse, Flint Island	0
Corona $\frac{1}{16}$ radius from sun	13
Corona $\frac{1}{4}$ radius from sun	4
Corona $\frac{3}{4}$ radius from sun	0

Proportion of rays which asphaltum transmits.

Source.	Determination.		Mean (weighted).
	I.	II.	
Sun $\frac{1}{16}$ radius from limb	0.333	0.331	0.332
Corona $\frac{1}{16}$ radius from limb	.343	484	.364
Corona $\frac{1}{4}$ radius from limb	.387	a.323	.362
Moon at night			.5
Sky, zenith day			.23

[a] This observation is entitled to only half the weight of the others.

Discussion of the results.

When we recall the extreme brightness of the sky within a single degree of the sun, as compared with that 20° away, and consider also the figures just given, it seems very unlikely that the corona will ever be observed without an eclipse.

The nature of the radiation of the inner corona has been supposed by some to be principally reflected solar radiation, by others to be principally due to the incandescence of particles heated by reason of their proximity to the sun, by others to be principally luminescence perhaps similar to the aurora, and by some as a combination of all of these kinds of radiation.

The spectrum of the corona is mainly continuous, but has some inconspicuous bright lines, and in its outer part has dark solar lines. Undoubtedly there is sunlight reflected by the matter of the corona, and no less surely the corona

must be hot. As for the idea of luminescence by electrical discharge, though the streamers of the corona are a reminder of the aurora, one hesitates to recommend an explanation involving a thing so little understood, so that we will here speak only of the incandescence and reflection of the corona as sources of its brightness. The bolometric results indicate that the coronal radiation differs but little in quality from that of the sun, and is, in fact, far richer than the reflected rays of the moon in visible light, although less rich than skylight.

These results indicate that if produced by virtue of high temperature, the coronal radiation must have come from a source almost as hot as the sun, which is upward of 6,000° absolute. Such temperatures as this are too high for the existence of any known solids or liquids, unless under high pressures not found in the corona, so that if the light is due to the high temperature of the corona itself, the corona must apparently be gaseous. But if it is gaseous, its spectrum should consist chiefly of bright lines, and this is not the fact. Hence it would seem that the coronal radiation, if it is produced by temperature, has its source in the sun itself, and is merely reflected by the matter of the corona, like the light of our atmosphere. But if the coronal rays are reflected, they would be bluer than sunlight, if the material there is gaseous, and as they are not, the coronal material may be supposed to be composed of solid or liquid particles to a considerable extent. But it is objected that only the outer corona shows the characteristic dark lines of the solar spectrum, and that these are absent in the region of the corona now being considered. May it not be that the temperature of the inner corona is so high that gases are present there along with the solid and liquid particles, so that the bright-line spectrum of these gases may be present and be superposed upon the reflected solar spectrum? In this case the bright rays of incandescence would fall exactly upon the dark lines of the solar spectrum and tend to obliterate them. At points in the corona more remote from the sun the gases would cool to liquid drops, or solid particles, or become excessively rare, so that the bright-line spectrum of incandescent gas would fade away, leaving the dark lines of the reflected solar spectrum predominant.

This line of explanation seems to me to accord with the facts observed, but I give it merely as a suggestion.

4. MOUNT WILSON OBSERVATIONS.

Great advantage having been found in 1905 and 1906 in making "solar-constant" investigations on Mount Wilson as well as in Washington, and strong evidence having been secured there of the considerable variability of the sun, it was concluded to continue in 1908 the expedition to Mount Wilson in order to secure as many observations of the "solar constant" as possible for the study of solar changes. As in former years, other kinds of measurements were contemplated, notably on the brightness of the sky and on the reflection of the clouds. The expedition, in charge of the writer, and including also Mr. L. B. Aldrich, of Madison, Wis., reached Mount Wilson on May 11, 1908. "Solar-constant" observations were begun on May 19 and have been made ever since daily when the sky permitted. Unfortunately the sky has been less clear on Mount Wilson than in other years, but nevertheless a great number of observations have been made.

The apparatus employed for observing the eclipse on Flint Island has been erected on Mount Wilson on the tower built for the Smithsonian expedition in 1906, and with this apparatus some of the observations of the brightness of the sky have already been made. It is expected to continue these measurements and others on the reflecting power of the clouds during the stay of the expedition.

A new and greatly improved copy of the standard water-flow pyrheliometer was constructed in Washington by the observatory instrument maker, Mr. A. Kramer, and is being installed on Mount Wilson.

The frequent observation of the "solar constant" during a period of years at least equal to the sun-spot cycle was regarded by the late director, Mr. Langley, as a research of great importance. Having proved by the expeditions of 1905 and 1906 that the variation of solar radiation is highly probable, and also that numerous days suitable for "solar-constant" observations were found in the months from May to November on Mount Wilson, it is now proposed to erect on a small, well-isolated plat of ground leased from the Carnegie Institution a fireproof observing shelter to be occupied by Smithsonian observers each year during the months mentioned. This improvement of equipment there is made necessary by the unsightly appearance and rapid deterioration of the wooden sheds now occupied by the Smithsonian expedition and also by the rapid development of electrical and other installation by the Carnegie solar observatory too near the present location for the long continuance of good work.

It is strongly hoped that the way may become clear for the continuance of "solar-constant" observations in the months from November to May either by the Smithsonian or other observers at a station equally as favorable for those months as Mount Wilson in summer.

Respectfully submitted.

C. G. ABBOT, *Director.*

Mr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix VI.

REPORT ON THE LIBRARY.

Sir: I have the honor to present the following report on the operations of the library of the Smithsonian Institution for the fiscal year ending June 30, 1908:

The accession book of the Smithsonian deposit, Library of Congress, shows that there have been recorded 1,744 volumes, 19,079 parts of volumes, 3,147 pamphlets, and 807 charts, making a total of 24,777 publications. The accession numbers run from 482,317 to 488,288. Of these publications a few needed for the scientific work of the Institution have been held, while the larger number has been sent to the Library of Congress.

In transmitting these publications to the Library of Congress 164 boxes have been used, and it is estimated that they contained the equivalent of 6,560 volumes. The actual number of publications sent, which includes parts of periodicals, pamphlets, and volumes, was 25,524. These two counts do not include public documents presented to the Smithsonian Institution, sent direct to the Library of Congress as soon as received, without stamping or recording, or public documents and other gifts to the Library of Congress received through the international exchange service, or publications requested to complete sets in the Smithsonian deposit at the Library of Congress, which have been transmitted separately.

The records of the libraries of the office, Astrophysical Observatory, and the National Zoological Park show that there have been received 889 volumes and pamphlets, 2,428 parts of volumes and charts, making a total of 3,317 and a grand total, including the publications for the Smithsonian deposit, of 28,094.

The parts of serial publications that were entered on the card catalogue numbered 32,454, and 1,310 slips for completing volumes were made, together with 480 cards for new periodicals and annuals which were added to the permanent record from the periodical recording desk.

Inaugural dissertations and academic publications were received from universities at the following places:

Basel	Heidelberg	Rostock
Berlin	Helsingfors	Strassburg
Bern	Jena	Toulouse
Bonn	Königsberg	Utrecht
Dorpat	Leipzig	Zurich
Erlangen	Louvain	
Giessen	Philadelphia	

The technical high schools at Berlin, Darmstadt, Dresden, and Karlsruhe have also sent publications of the same character.

In continuing the plan to effect new exchanges and to secure missing parts to complete sets, 2,161 letters were written, resulting in about 500 new periodicals being added to the lists and the receipt of about 1,559 parts lacking in the sets were secured, which partially filled up or entirely completed the various series of publications in the Smithsonian deposit. In writing for the missing parts of publications needed to complete these sets, the library has had assistance

from the international exchange service of the Institution. The replies to these requests are now coming in, but it is too early to state definitely the measure of success attained as a result of these efforts. In addition the Institution has, through the medium of the international exchange service, sent out requests for government documents and serial publications needed to complete the sets in the Library of Congress, and with this end in view letters have been written to Bavaria, the Province of Buenos Aires, Costa Rica, Greece, Guatemala, Honduras, Newfoundland, Nicaragua, Japan, Russia, and Salvador.

In the reading room there were issued 20 bound volumes of periodicals and 3,285 parts of scientific periodicals and popular magazines, making a total of 3,305. The various bureaus of the Government have continued to use these publications and those in the sectional libraries of the Institution. In the main however, the consultations have been by members of the staff.

The mail receipts numbered 33,106 packages. The publications contained therein were stamped and distributed for entry from the mail desk. About 4,372 acknowledgments were made on the regular form, which is in addition to those for publications received in response to the requests of the Institution for exchange.

The following changes were made in the routine of the library, commencing with the first of the calendar year, in accordance with the secretary's instructions:

The filing of letters was changed from the alphabetical arrangement to the filing by number with a card-catalogue index. The recording of the purchase of books on sheets was discontinued and the card record only was retained. The record of exchange publications with booksellers heretofore kept in the office of the correspondence and documents of the museum was transferred to the Smithsonian library, and a book containing the debit and credit account has been commenced.

The employees' library.—The books added to the library were 398, and of these 13 were purchased and 385 were presented by Miss Lucy H. Baird, of Philadelphia, Pa. In this collection were a large number of the older standard novels, together with bound volumes of periodicals, such as the Century, Harper's, Atlantic Monthly, etc., some of the sets being quite complete. The number of books borrowed was 1,813, and the sending of a selected number of books from this library to the National Zoological Park and the Bureau of American Ethnology each month has been continued. This library has been fortunate for a number of years in having the volunteer services of Miss Margaret C. Dyer, which were rendered in an intelligent and faithful manner, but upon her resignation, which took effect on June 1, the care of the books was transferred to Miss Elsie V. H. Baldwin, who volunteered her services.

The art room.—The work of cataloguing the collections of engravings in the art room has been continued, but the greater part of the time was devoted to separating the various collections and checking them on available memorandum lists.

In addition to the regular work in the library the assistant librarian, Mr. Paul Brockett, has reconstructed the memorandum list of the collection of engravings and works of art which were purchased by the Smithsonian Institution in 1849 from Mr. George Perkins Marsh. Whatever catalogue may have been made of this collection at the time of the purchase was destroyed in the fire of 1866. The list as reconstructed gives the full title of almost all the books and indicates the number of engravings that should be in the collection. In addition to the reconstruction of this list, Mr. Brockett has been engaged in preparing a bibliography of aeronautical literature which is

to include the indexing of papers in periodicals and proceedings of aeronautical societies, together with books and separate pamphlets on the subject. The work of indexing is nearing completion.

The American Historical Association.—The exchange of the annual reports of the American Historical Association from the allotment agreed upon for that purpose was continued, with the result that a large number of publications of historical societies throughout the world have been received.

The museum library.—The National Museum library has continued to receive from Prof. Otis T. Mason and Dr. C. D. White many gifts of scientific publications which are of great value to the museum library in completing sets and filling in the series of authors' separates. Mr. William Schaus has added materially to the books in the sectional library of the division of insects, which are needed in the work on his collections of insects presented to the museum. Dr. Charles W. Richmond has presented another installment of books and pamphlets, one of the collections in this gift being the Thunberg dissertations, which are for the most part rare and difficult to obtain. He is making efforts to bring together a complete set.

The library was unfortunate in losing by resignation the capable and valued services of Miss Margaret C. Dyer, who had been assistant in the museum library for a number of years.

The library of the museum has benefited by the plan adopted by the International Catalogue of Scientific Literature of sending to authors lists of their scientific writings that have been entered in the catalogue and requesting any that have not been cited, as the larger number of responses received are in the form of separates from periodicals, journals, etc., which are no longer desired for the Smithsonian deposit.

In the museum library there are now 33,564 volumes, 52,112 unbound papers, and 108 manuscripts. The additions during the year consisted of 3,257 books, 4,470 pamphlets, and 247 parts of volumes. There were catalogued 1,000 books, of which 39 belonged to the Smithsonian library; 2,257 complete volumes of periodicals, and 4,056 pamphlets, of which 26 belonged to the Smithsonian library.

Attention has been given to the preparation of volumes for binding, with the result that 1,086 books were sent to the government bindery.

The number of books, periodicals, and pamphlets borrowed from the general library amounted to 39,556, including 10,314, which were assigned to the sectional libraries. This does not include, however, the large number of books consulted in the library but not withdrawn.

The sectional libraries established in the museum have remained the same, the complete list now standing as follows:

Administration.	Geology.	Paleobotany.
Administrative Assistant.	History.	Parasites.
Anthropology.	Insects.	Photography.
Biology.	Mammals.	Physical Anthropology.
Birds.	Marine Invertebrates.	Prehistoric Archeology.
Botany.	Materia Medica.	Reptiles.
Comparative Anatomy.	Mesozoic fossils.	Invertebrate Paleontology.
Editor.	Mineralogy.	Superintendent.
Ethnology.	Mollusks.	Taxidermy.
Fishes.	Oriental Archeology.	Technology.

The following table summarizes all the accessions during the year except for the Bureau of American Ethnology, which is separately administered:

Smithsonian deposit in the Library of Congress	24,777
Office, Astrophysical Observatory, National Zoological Park, International Exchanges	3,317
United States National Museum library	7,974
Total	36,068

Respectfully submitted.

CYRUS ADLER,
Assistant Secretary, in charge of Library and Exchanges.

Dr. CHARLES D. WALCOTT,
Secretary, Smithsonian Institution.

Appendix VII.

REPORT ON THE INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

Sir: I have the honor to submit the following report on the operations of the United States Bureau of the International Catalogue of Scientific Literature for the fiscal year ending June 30, 1908.

The organization known as the "International Catalogue of Scientific Literature" has by means of the cooperation of all of the principal countries of the world been publishing since 1901, in seventeen annual volumes, a classified index catalogue of the current scientific literature of the world. Each country collects, indexes, and classifies the scientific literature published within its borders and furnishes to the central bureau in London the material thus prepared for publication in the annual volumes.

The cost of preparation is borne by the countries taking part in the work, in the great majority of cases the support being derived through direct governmental grants. The entire cost of printing and publishing is borne by the subscribers to the catalogue. The bureau for the United States contributes yearly about 11 per cent of the entire work.

The allotment for the present fiscal year made by Congress for this purpose was $5,000, the same as for previous years. Five persons are regularly employed in the preparation of the classified index to American scientific literature.

During the year there were 28,528 references to American scientific literature completed and forwarded to the central bureau in London as follows:

Literature of 1901	408
Literature of 1902	523
Literature of 1903	366
Literature of 1904	956
Literature of 1905	5,629
Literature of 1906	7,217
Literature of 1907	13,429
Total	28,528

Twenty-one volumes of the catalogue were received and delivered to subscribers in this country, as follows:

Fifth Annual Issue—Mechanics, Physics, Chemistry, Meteorology, Mineralogy, General Biology, Botany, Zoology, Anatomy, Anthropology, Physiology, and Bacteriology, completing the issue.

Sixth Annual Issue—Mathematics, Mechanics, Astronomy, Meteorology, Mineralogy, Geology, Geography, Zoology, and Anatomy.

All sections of the civilized world are represented in this enterprise, as shown by the following list of the regional bureaus now established and regularly furnishing to the London central bureau classified citations of scientific papers published within their domains: Austria, Belgium, Canada, Cuba, Denmark, Egypt, Finland, France, Germany, Greece, Holland, Hungary, India and Ceylon, Italy, Japan, Mexico, New South Wales, New Zealand, Norway, Poland (Aus-

trian, Russian, and Prussian), Portugal, Queensland, Russia, South Africa, South Australia, Spain, Sweden, Switzerland, the United States of America, Victoria, and Western Australia.

Much interest has attached to the consolidation of the famous zoological yearbook known as the "Zoological Record" with the zoology volume of the International Catalogue of Scientific Literature. By an agreement with the Zoological Society of London a plan was consummated whereby the International Catalogue agreed to compile through its regional bureaus the index to the world's zoological literature; the Zoological Society of London undertaking on its part to revise and edit the material thus furnished, the staff of specialists previously intrusted with the preparation of the Zoological Record being retained as editors. The International Catalogue of Scientific Literature assumed all responsibilities connected with the publication and sale of the combined volumes.

If the amalgamation of interests above referred to meets with continued success it is to be earnestly hoped that the numerous other independent scientific bibliographies and yearbooks may gradually become similarly associated with the International Catalogue, for great waste of energies and money result in the production of similar publications covering identical fields.

Since the first volumes were published the bulk of the catalogue has been increasing each year. The fifth annual issue aggregated 12,000 printed pages, which is 2,000 pages larger than the fourth issue. At present the actual expenses of the London central bureau for editing and printing alone so nearly reach the total receipts derived from subscriptions that it has been found necessary to limit the work strictly to its originally defined scope and also to be most careful in the use of cross references in preparing the subject catalogue.

In order not to limit the usefulness of the index, condensation has to be most carefully done, and more time is required in careful selection and specific classification than would be the case if economy of printed space were not so imperative.

However, this extreme care in classification is beneficial to both the publishers and the users of the catalogue, for it necessitates in the classifier a most thorough grasp of the subject of each paper in order that a specific place in the subject catalogue may be assigned, rigidly excluding all unessential or general cross references, thus, while printed space is economized, the users of the work are saved all unnecessary labor in looking up general references not directly treating the special subject in which they are concerned.

In the sundry civil bill approved May 27, 1908, $5,000 was appropriated to carry on the work for the fiscal year ending June 30, 1909.

Respectfully submitted.

CYRUS ADLER,
Assistant Secretary, in charge of Library and Exchanges.

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

Appendix VIII.

REPORT ON THE PUBLICATIONS.

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and its branches during the fiscal year ending June 30, 1908:

There have been distributed a total of 5,624 volumes and separates in the series of "Smithsonian Contributions to Knowledge," 25,888 in the series of "Smithsonian Miscellaneous Collections," 22,945 in the series of "Smithsonian Annual Reports," and 4,939 in the series of "Special Publications." In addition thereto there were 499 publications not included in the Smithsonian series that were sent out by the Institution, making a grand total of 59,895, an increase of 17,974 over the previous year, and the largest number distributed during the last five years with the exception of the year 1905.

I. SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

In the series of Smithsonian Contributions to Knowledge, three memoirs, which were in press at the close of the last fiscal year, have been published.

1692. Glaciers of the Canadian Rockies and Selkirks. Report of the Smithsonian Expedition of 1904. By William Hittell Sherzer, Ph. D. Quarto. Pages xii, 135, with 42 plates. Part of Volume XXXIV.

In this memoir Doctor Sherzer discusses the indicated physiographic changes in the region during the Mesozoic and Pleistocene periods; the question of precipitation of snow and rain, and the effect of climatic cycles on glacial movements; the structure of the ice as to stratification, shearing, blue bands, ice dykes, glacial granules, and the possible methods of their development; the theories of glacial motion as applied to these glaciers; and the cause of the richness and variety of coloring of glaciers and glacial lakes.

1718. The Young of the Crayfishes Astacus and Cambarus. By E. A. Andrews. Quarto. Pages 79, with 10 plates. Part of Volume XXXV.

In this memoir there is described and illustrated the young of two kinds of crayfishes, one from Oregon and one from Maryland, representing the two most diverse forms in North America. The first, second, and third larval stages are determined, and there is described the hitherto unknown nature of successive mechanical attachments of the offspring to the parent.

1723. The Apodous Holothurians. A Monograph of the Synaptidæ and Molopadiidæ. Including a report on the representatives of these families in the collections of the United States National Museum. By Hubert Lyman Clark. Quarto. Pages 231, with 13 plates. Part of Volume XXXV.

This memoir gives a summary of present knowledge of the two families of sea cucumbers, which lack tube feet.

There was in press at the close of the year, to meet the increasing demand for the work, a reprint of Mr. Langley's memoir on "The Internal Work of the Wind," originally published in 1893 in quarto form as No. 884, Smithsonian Contributions to Knowledge. To the present edition was added as an appendix a translation of the "Solution of a Special Case of the General Problem," by Réné de Saussure, which appeared in 1893 with "Le Travail Intérieur du Vent" in Revue de l'Aéronautique Théorique et Appliqué, Paris, pages 58–68.

II. SMITHSONIAN MISCELLANEOUS COLLECTIONS.

In the series of Smithsonian Miscellaneous Collections, Volumes L and LII, there were published 32 papers in the Quarterly Issue, Volume IV, parts 2, 3, and 4, and Volume V, part 1. There were also published, in the regular series of the Smithsonian Miscellaneous Collections, 8 papers, appearing in Volumes XLIX, LI, and LIII.

In the Quarterly Issue series:

1724. The Air Sacs of the Pigeon. By Bruno Müller. Published January 16, 1908. Octavo. Pages 365–414 (Volume IV, part 3), with Plates XLV–XLIX. Hodgkins fund.

1725. Smithsonian Miscellaneous Collections. Quarterly Issue. Volume IV, part 2 (containing Nos. 1726–1735). Octavo. Pages 133–288, with Plates XV–XXII.

1726. Notes on a Small Collection of Mammals from the Province of Kan-Su, China. By Marcus Ward Lyon, jr. Published July 9, 1907. Octavo. Pages 133–138, with Plates XV–XVI.

1727. Descriptions of New Species of Shells, Chiefly Buccinidæ, from the Dredgings of the U. S. S. *Albatross* during 1906 in the Northwestern Pacific, Bering, Okhotsk, and Japanese seas. By William Healey Dall. Published July 9, 1907. Octavo. Pages 139–173.

1728. A New Larch from Alaska. By W. F. Wight. Published July 10, 1907. Octavo. Page 174, with Plate XVII.

1729. The Lumpsucker; its Relationship and Habits. By Theodore Gill. Published July 10, 1907. Octavo. Pages 175–194.

1730. New Plants of the Pacific Slope, with Some Revisions. By Charles V. Piper. Published August 23, 1907. Octavo. Pages 195–202.

1731. Contributions to the Study of the Canyon Diablo Meteorites. By George P. Merrill and Wirt Tassin. Published September 12, 1907. Octavo. Pages 203–215 with Plates XVIII–XXI.

1732. Louis Agassiz. By Charles Doolittle Walcott. Published September 12, 1907. Octavo. Pages 216–218, with Plate XXII.

1733. Terrestrial Isopods of the Family Eubelidæ, collected in Liberia by Dr. O. F. Cook. By Harriet Richardson. Published September 12, 1907. Octavo. Pages 219–247.

1734. The Relations of the Chinese to the Philippine Islands. By Berthold Laufer. Published September 13, 1907. Octavo. Pages 248–284.

1735. Notes to Quarterly Issue. Volume IV, part 2. Octavo. Pages 285–287.

1772. Smithsonian Miscellaneous Collections. Quarterly Issue. Volume IV, part 3 (containing Nos. 1773–1779, and 1724). Octavo. Pages 289–418, with Plates XXIII–XLIX.

1773. Excavations at Casa Grande, Arizona, in 1906–7. By J. Walter Fewkes. Published October 25, 1907. Octavo. Pages 289–329, with Plates XXIII–XL.

1774. Nopalea guatemalensis, a New Cactus from Guatemala. By J. N. Rose. Published October 28, 1907. Octavo. Page 330, with Plates XLI–XLII.

1775. Pereskiopsis, a New Genus of Cactaceæ. By N. L. Britton and J. N. Rose. Published October 28, 1907. Octavo. Pages 331–334, with Plates XLIII–XLIV.

1776. Two New Ferns of the Genus Lindsæa. By Lucien M. Underwood and William R. Maxon. Published October 28, 1907. Octavo. Pages 335–336.

1777. Five New Recent Crinoids from the North Pacific Ocean. By Austin Hobart Clark. Published October 29, 1907. Octavo. Pages 337–342.

1778. New Genera of Recent Free Crinoids. By Austin Hobart Clark. Published October 29, 1907. Octavo. Pages 343–364.

1779. Notes to Quarterly Issue. Volume IV, part 3. Octavo. Pages 415–416.

1780. Smithsonian Miscellaneous Collections. Quarterly Issue. Volume IV, part 4 (containing Nos. 1781–1788). Octavo. Pages i–viii, 419–558, with Plates L–LXXV.

1781. New and Characteristic Species of Fossil Mollusks from the Oil-bearing Tertiary Formations of Santa Barbara County, California. By Ralph Arnold. Published December 13, 1907. Octavo. Pages 419–448, with Plates L–LVIII.

1782. On the Occurrence of Remains of Fossil Cetaceans of the Genus Schizodelphis in the United States, and on Priscodelphis (?) crassangulum Case. By Frederick W. True. Published January 27, 1908. Octavo. Pages 449–460, with Plates LIX–LX.

1783. The Meteor Crater of Canyon Diablo, Arizona; its History, Origin, and Associated Meteoric Irons. By George P. Merrill. Published January 27, 1908. Octavo. Pages 461–498, with Plates LXI–LXXV.

1784. Notes on Gonidea angulata Lea, a Fresh-water Bivalve, with Description of a New Variety. By William H. Dall. Published January 28, 1908. Octavo. Pages 499–500.

1785. A New Species of Cavolina, with Notes on Other Pteropods. By William H. Dall. Published January 28, 1908. Octavo. Pages 501–502.

1786. A Preliminary Treatment of the Opuntioideæ of North America. By N. L. Britton and J. N. Rose. Published February 20, 1908. Octavo. Pages 503–539.

1787. Observations on the Mosquitoes of Saskatchewan. By Frederick Knab. Published February 20, 1908. Octavo. Pages 540–547.

1788. Notes to Quarterly Issue. Volume IV, part 4. Octavo. Pages 548–550.

1789. Smithsonian Miscellaneous Collections (Quarterly Issue, Volume IV), Volume L. Octavo. Pages i–viii, 1–558, with Plates I–LXXV.

1792. Smithsonian Miscellaneous Collections, Quarterly Issue. Volume V, part 1 (containing Nos. 1793–1802). Octavo. Pages 1–119, with Plates I–VIII.

1793. The Cretaceous Fishes of Ceará, Brazil. By David Starr Jordan and John Casper Branner. Published April 29, 1908. Octavo. Pages 1–30, with Plates I–VIII.

1794. Observation of the Total Solar Eclipse of January 3, 1908: A Bolometric Study of the Solar Corona. By C. G. Abbot. Published April 30, 1908. Octavo. Pages 31–48.

1795. Report on a Trip for the Purpose of Studying the Mosquito Fauna of Panama. By August Busck. Published May 1, 1908. Octavo. Pages 49–78.

1796. Carl Ludwig Rominger. By George P. Merrill. Published May 1, 1908. Octavo. Pages 79–82.

1797. Edward Travers Cox. By George P. Merrill. Published May 1, 1908. Octavo. Pages 83–84.

1798. An Apparently New Protoblattid Family from the Lower Cretaceous. By Evelyn Groesbeeck Mitchell. Published May 27, 1908. Octavo. Pages 85–86.

1799. Necessary Changes in the Nomenclature of Starfishes. By Walter K. Fisher. Published May 27, 1908. Octavo. Pages 87–94.

1800. Identity of a Supposed Whitefish, Coregonus angusticeps Cuvier and Valenciennes, with a Northern Cyprinid, Platygobio gracilis (Richardson). By William Converse Kendall. Published May 27, 1908. Octavo. Pages 95–100.

1801. The Millers-thumb and its Habits. By Theodore Gill. Published June 18, 1908. Octavo. Pages 101–116.

1802. Notes to Quarterly Issue. Volume V, part 1. Octavo. Pages 117–118.

There were about to go to press in the Quarterly Issue at the close of the fiscal year: Indians of Peru, by Charles C. Eberhardt; and the Nettelroth Collection of Invertebrate Fossils, by R. S. Bassler.

In the regular series of Smithsonian Miscellaneous Collections the following have been published:

1717. Report on the Crustacea (Brachyura and Anomura) Collected by the North Pacific Exploring Expedition, 1853–1856. By William Stimpson. Octavo. Pages 240, with Plates I–XXVI. Part of Volume XLIX.

This work, which was in press at the close of the fiscal year 1907, was edited by Miss Mary J. Rathbun. Its scope and the causes for delay in its publication were discussed in the report for last year.

1720. Samuel Pierpont Langley, Secretary of the Smithsonian Institution, 1887–1906. Memorial meeting December 3, 1906. Addresses by Doctor White, Professor Pickering, and Mr. Chanute. Octavo. Pages 49. Part of Volume XLIX.

1741. Smithsonian Miscellaneous Collections. Volume XLIX (containing Nos. 1584, 1652, 1717, 1720, and 1721). (Cover, title-page, advertisement, and table of contents.) Octavo. Pages v.

1791. The Development of the American Alligator. By Albert M. Reese. Octavo. Pages 66, with Plates I–XXIII. Part of Volume LI.

1803. The Taxonomy of the Muscoidean Flies, including Descriptions of New Genera and Species. By Charles H. T. Townsend. Octavo. Pages 138. Part of Volume LI.

1804. Cambrian Geology and Paleontology. No. 1, Nomenclature of Some Cambrian Cordilleran Formations. By Charles D. Walcott. Octavo. Pages 1–12. Part of Volume LIII.

1805. Cambrian Geology and Paleontology. No. 2, Cambrian Trilobites. By Charles D. Walcott. Octavo. Pages 13–52, with plates 1–6. Part of Volume LIII.

1807. Smithsonian Exploration in Alaska in 1907 in Search of Pleistocene Fossil Vertebrates. By Charles W. Gilmore. Octavo. Pages 38, with Plates I–XIII. Part of Volume LI.

At the close of the fiscal year there were in press in the regular series of Smithsonian Miscellaneous Collections the following papers, which continue the studies of Cambrian Geology and Paleontology by Charles D. Walcott: No. 3, Cambrian Brachiopoda: Descriptions of New Genera and Species; No. 4, Classification and Terminology of the Cambrian Brachiopoda; and No. 5, Cambrian Sections of the Cordilleran Area. These papers will form parts of Volume LIII of the Smithsonian Miscellaneous Collection, which it is proposed to devote entirely to these studies.

There was also in press the Smithsonian Mathematical Tables: Hyperbolic Functions, by George F. Becker and C. E. Van Orstrand.

III. SMITHSONIAN ANNUAL REPORTS.

The annual report for 1906 was in type at the close of the last fiscal year, but final printing, binding, and delivery were not completed until October.

The secretary's report for 1907, forming a part of the annual report of the Board of Regents to Congress, was printed as usual in pamphlet form in November, 1907, for the use of the board, and a larger edition was afterwards printed for public distribution, as follows:

1737. Report of the Secretary of the Smithsonian Institution for the year ending June 30, 1907. Octavo. Pages 95.

The full report for 1907 was in type at the close of the fiscal year, though only partly paged. The general appendix contains the following papers:

The Steam Turbine on Land and Sea. By Charles A. Parsons.

The Development of Mechanical Composition in Printing. By A. Turpain.

Some Facts and Problems Bearing on Electric Trunk Line Operation. By Frank J. Sprague.

Recent Contributions to Electric Wave Telegraphy. By J. A. Fleming.

On the Properties and Natures of Various Electric Radiations. By W. H. Bragg.

Progress in Electro-Metallurgy. By J. B. C. Kershaw.

Advances in Color Photography. By T. W. Smillie.

The Structure of Lippmann's Heliochromes. By S. R. Cajal.

Bronze in South America before the Arrival of the Europeans. By A. de Mortillet.

Some Opportunities for Astronomical Work with Inexpensive Apparatus. By George E. Hale.

The Progress of Science as Illustrated by the Development of Meteorology. By Cleveland Abbe.

Geology of the Inner Earth: Igneous Ores. By J. W. Gregory.

The Salton Sea. By F. H. Newell.

Inland Waterways. By George G. Chisholm.

The Present Position of Paleozoic Botany. By D. H. Scott.

The Zoological Gardens and Establishments of Great Britain, Belgium, and the Netherlands. By Gustave Loisel.

Systematic Zoology; its Progress and Purpose. By Theodore Gill.

The Genealogical History of the Marine Mammals. By O. Abel.

The People of the Mediterranean. By Theobald Fischer.

Ancient Japan. By E. Baelz.

The Origin of Egyptian Civilization. By Edouard Naville.

The Fire Piston. By Henry Balfour.

The Origin of the Canaanite Alphabet. By Franz Prætorius.

Three Aramaic Papyri from Elephantine. By Eduard Sachau.

The Problem of Color Vision. By J. M. Dane.

Immunity in Tuberculosis. By Simon Flexner.

The Air of the New York Subway. By George A. Soper.

Marcelin Berthelot. By Camille Matignon.

Linnæan Memorial Address. By Edward L. Greene.

IV. SPECIAL PUBLICATIONS.

As a special publication there was issued for distribution to correspondents the following:

1806. Classified list of Smithsonian Publications Available for Distribution, May, 1908. Octavo. Pages 40.

There was also printed for general distribution, without a serial number, a duodecimo pamphlet of 3 pages entitled "The International Catalogue of Scientific Literature, Regional Bureau for the United States." This pamphlet gives the purpose, briefly describes the work, and summarizes the results of the International Catalogue.

A similar pamphlet went to press at the close of the fiscal year: "Rules for the Abbreviation of Titles of Scientific Periodicals in Publications of the Smithsonian Institution and its branches."

V. PUBLICATIONS OF THE UNITED STATES NATIONAL MUSEUM.

The publications of the National Museum are: (*a*) The annual report, forming a separate volume of the Report to Congress by the Board of Regents of the Smithsonian Institution; (*b*) The Proceedings of the United States National

Museum; (*c*) The Bulletin of the United States National Museum; and (*d*) the Contributions from the United States National Herbarium.

The publications issued during the year are enumerated in the Report on the National Museum. These included the Annual Report of the Smithsonian Institution for the year ending June 30, 1907, part 2, National Museum, published as serial number 1790 in the Smithsonian series; Volume XXXIII of the Proceedings; Bulletins 59, 60, and 61, and a reprint of Bulletin 39; Volume X, parts 5, 6, and 7, and Volume XII, parts 1, 2, and 3, of the Contributions from the United States National Herbarium, including a special edition of Volume XII, part 2. At the close of the fiscal year Volume XXXIV of the Proceedings and Bulletin 62 were in course of preparation.

VI. PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

The Twenty-fifth Annual Report of the Bureau of American Ethnology was issued in September, and Bulletins 33, 35, and 36 in November, February, and June, respectively, with the usual separates. A special publication was issued in June under the title "Indian Missions." At the close of the year there were in course of preparation, besides the twenty-sixth annual report, Bulletins 34, Physiological and Medical Observations Among the Indians of Southwestern United States and Northern Mexico (Hrdlička); 38, Unwritten Literature of Hawaii (Emerson); 39, Tlingit Texts and Myths (Swanton); and 40, Handbook of American Indian Languages, Part I (Boas).

VII. PUBLICATIONS OF THE SMITHSONIAN ASTROPHYSICAL OBSERVATORY.

Volume II of the Annals of the Astrophysical Observatory, by C. G. Abbot and F. E. Fowle, jr., was published in quarto form (pages xi, 245, with 29 plates). (Smithsonian serial No. 1738.)

The preface of the volume states:

"The Astrophysical Observatory of the Smithsonian Institution was founded through the efforts of the late Secretary Langley, who was its director until his death. The research described in the present volume is a continuation of the work on the relations of the sun to climate and life upon the earth, of which he was a brilliant pioneer investigator.

"Mr. Langley expressed the hope that careful study of the radiation of the sun might eventually lead to the discovery of means of forecasting climatic conditions for some time in advance. It is believed that the present volume will aid materially to show how far that hope may be justified, for it contains careful and comparable measurements of the solar radiation, extending over several years. These indicate that the sun's radiation alters in its intensity from time to time, and that these alterations are sufficient to affect the temperature of the earth very appreciably."

A short note on the "Reflecting power of clouds" to accompany Volume II of the annals was in press at the close of the year.

VIII. REPORT OF THE AMERICAN HISTORICAL ASSOCIATION.

Volume II of the annual report of the American Historical Association for the year 1905, comprising a complete bibliography of the publications of American historical societies for more than a century, was issued in February. The annual report for 1906 had gone to press at the close of the fiscal year.

IX. REPORT OF THE DAUGHTERS OF THE AMERICAN REVOLUTION.

The Tenth Report of the National Society of the Daughters of the American Revolution was received from the society and submitted to Congress in accordance with law on March 25.

X. SMITHSONIAN COMMITTEE ON PRINTING.

The editor has served as secretary of the Smithsonian advisory committee on printing and publication. To this committee have been referred the manuscripts proposed for publication by the various branches of the Institution, and also those offered for printing in the quarterly issue of the Smithsonian Miscellaneous Collections. The committee has likewise passed upon blank forms for current use in the Institution and its branches. The committee considered and reported to the Secretary on various questions relating in general to printing and publication. Twenty-six meetings were held during the year and 137 papers were reported on.

The committee formulated the following rules for abbreviation of titles:

RULES FOR THE ABBREVIATION OF TITLES OF SCIENTIFIC PERIODICALS IN PUBLICATIONS OF THE SMITHSONIAN INSTITUTION AND ITS BRANCHES.

1. In abbreviating words in titles stop before the second vowel, unless the resulting abbreviation would contain but one consonant, in which case stop before the third vowel.

Examples.

Abhandlung	Abh.
Academy	Acad.
Bericht	Ber.

Explanations and exceptions.

A. The following words have irregular abbreviations to avoid confusion with other words having the same beginning, but different termination, or for other reasons:

Analytical	Analyt.
Architecture (or -al)	Archit.
Astrophysics (or -ical)	Astrophys.
Bibliography (or -ical)	Bibliogr.
College. (Not abbreviated.)	
Columbian	Columb.
Ethnography (or -ical)	Ethnogr.
Experimental	Exper.
Herausgegeben	Hrsg.
Industrial	Indust.
Manufactures (or -ing)	Mfr.
Mining	Mg.
Monthly	Mo.
Monograph	Monogr.
Philosophy (or -ical)	Philos.
Physiology (or -ical)	Physiol.
Public (or publication)	Pub.
Repertorium	Repert.
Repository	Repos.
Science (or scientific)	Sci.
Sociology	Sociol.
Statistics (or -ical)	Statist.
Telephone (or -ic)	Teleph.

B. The following abbreviations in common use, also the ordinary post-office abbreviations for States of the United States, are allowable: R. R. (railroad); C. R. (comptes rendus); k. k. (kaiserlich und königlich); U. S.

(United States); N. S. W. (New South Wales); Lond. (London); Par. Paris); Ber. (Berlin); St. Petersb. (St. Petersburg); Phila. (Philadelphia), etc.

C. Compound German, Norwegian, and Swedish words may be abbreviated (*a*) by adding to the first component the consonant or consonants immediately following, or (*b*) by abbreviating each component according to rule 1 and connecting them by hyphens.

Examples.

Monatsbericht.....Monatsb. or Mon.-Ber.
Naturvidenskabeligt.....Naturv. or Nat.-Vid.
Landhushållning.....Landh. or Land-Hush.

D. Numerals occurring in titles should be treated thus:

Fiftieth.....50th.
Fifteenth.....15th.
Deuxième.....2me.
Vierte.....4te, etc.

2. All articles, prepositions, and conjunctions are to be omitted, except "and" and "for," which may be retained when necessary for clearness.

Examples.

Bollettino dei Musei di Zoölogia ed Anatomia Comparata=Boll. Mus. Zoöl. ed Anat. Comp.

Proceedings of the Academy of Natural Sciences of Philadelphia=Proc. Acad. Nat. Sci. Phila.

Mémoires pour servir à l'Histoire Physique et Naturelle de la Suisse—Mém. Hist. Phys. et Nat. Suisse.

3. In abbreviated titles, the words should follow strictly the order of the full titles.

Examples.

Proceedings of the Biological Society of Washington=Proc. Biol. Soc. Washington; not Washington Biol. Soc. Proc.

Annales de la Société Entomologique de Paris=Ann. Soc. Ent. Paris; not Paris Ann. Soc. Ent.

4. (*a*) Words of one syllable, (*b*) titles consisting of a single word, (*c*) names of towns (except as indicated under rule 5), (*d*) names of persons (when unmodified), and (*e*) names of geological formations, are not to be abbreviated.

5. Whenever necessary for clearness any of the foregoing rules may be disregarded, but in such cases words should not be abbreviated.

XI. PRESS ABSTRACTS OF PUBLICATIONS.

Continuing the policy established in March, 1907, an editorial assistant has been engaged in preparing abstracts of such publications of the Institution and its branches as could be put in popular language for the use of newspapers throughout the country. There have also been sent out a number of brief accounts of current investigations and longer descriptions of the general work of the Institution, including that of the International Catalogue, the International Exchanges, the Astrophysical Observatory and other branches.

Respectfully submitted.

A. HOWARD CLARK, *Editor.*

Dr. CHARLES D. WALCOTT,
Secretary of the Smithsonian Institution.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDING JUNE 30, 1908.

To the Board of Regents of the Smithsonian Institution:

Your executive committee respectfully submits the following report in relation to the funds, receipts, and disbursements of the Institution, and a statement of the appropriations by Congress for the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, the Astrophysical Observatory, the International Catalogue of Scientific Literature, and the ruin of Casa Grande for the year ending June 30, 1908, together with balances of previous appropriations.

SMITHSONIAN INSTITUTION.

Condition of the fund July 1, 1908.

The permanent fund of the Institution and the sources from which it has been derived are as follows:

DEPOSITED IN THE TREASURY OF THE UNITED STATES.

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposit from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Part of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Deposit from savings of income, 1903		25,000.00
Residuary legacy of Thomas G. Hodgkins		7,918.69
Total amount of fund in the United States Treasury		944,918.69

OTHER RESOURCES.

Registered and guaranteed bonds of the West Shore Railroad Company, part of legacy of Thomas G. Hodgkins (par value)	42,000.00
Total permanent fund	986,918.69

Also four small pieces of real estate bequeathed by Robert Stanton Avery, of Washington, D. C.

That part of the fund deposited in the Treasury of the United States bears interest at 6 per cent per annum, under the provisions of the act of August 10, 1846, organizing the Institution, and an act of Congress approved March 12, 1894. The rate of interest on the West Shore Railroad bonds is 4 per cent per annum. The real estate received from Robert Stanton Avery is exempt from taxation and yields only a nominal revenue from rentals.

Statement of receipts and disbursements from July 1, 1907, to June 30, 1908.

RECEIPTS.

Cash on deposit in the United States Treasury July 1, 1907		$24,592.01
Interest on fund deposited in the United States Treasury, due July 1, 1907, and January 1, 1908	$56,582.52	
Interest on West Shore Railroad bonds to January 1, 1908	1,680.00	
Repayments, rentals, publications, etc	4,810.44	
Proceeds from claims in litigation	300.00	
		63,372.96
		87,964.97

DISBURSEMENTS.

Buildings, care and repairs		$5,457.35
Furniture and fixtures		1,645.84
General expenses:		
Salaries	$17,318.53	
Meetings	246.85	
Stationery	904.07	
Postage, telegraph, and telephones	365.90	
Freight	113.18	
Incidentals	1,133.72	
Stable	2,274.57	
		22,356.82
Library		2,351.65
Publications and their distribution:		
Miscellaneous collections	6,651.46	
Contributions to knowledge	4,785.63	
Reports	561.57	
Special publications	175.10	
Publication supplies	371.85	
Salaries	5,562.75	
		18,108.36
Explorations and researches		8,452.25
Hodgkins specific fund, researches and publications		2,629.18
International exchanges		4,142.49
Legal expenses		2,923.82
Apparatus		584.95
Gallery of Art		305.85
		68,958.56
Hamilton fund		240.00
		69,198.56
Balance, June 30, 1908, deposited with the Treasurer of the United States		18,766.41
		87,964.97

By authority, your executive committee employed Mr. J. E. Bates, a certified public accountant, to audit the receipts and disbursements of the Smithsonian Institution during the period covered by this report. His certificate of examination supports the foregoing statement, and reads as follows:

WASHINGTON, D. C., *October 1, 1908.*

The EXECUTIVE COMMITTEE, BOARD OF REGENTS,
Smithsonian Institution, Washington, D. C.

GENTLEMEN: I certify that I have examined the accounts and vouchers of the Smithsonian Institution for the fiscal year ending June 30, 1908, and find the following cash statement to be correct:

July 1, 1907, amount on hand	$24,592.01
RECEIPTS.	
Total receipts for year ending June 30, 1908	63,372.96
Total	87,964.97
DISBURSEMENTS.	
Total disbursements for year ending June 30, 1908	69,198.56
June 30, 1908, balance on hand	18,766.41
June 30, 1908, balance as per United States Treasurer's statement after deducting all outstanding checks unpaid	18,766.41

Respectfully, yours,

(Signed) J. E. BATES,
Public Accountant and Auditor.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Institution, and all payments are made by checks signed by the secretary.

The vouchers representing payments from the Smithsonian income during the year ending June 30, 1908, each of which bears the approval of the secretary, or, in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution, have been examined by the auditor in connection with the books of the Institution and found correct.

The expenditures made by the disbursing agent of the Institution and audited by the Auditor for the State and other Departments are reported in detail to Congress, and will be found in the printed document.

Your committee also presents the following summary of appropriations for the fiscal year 1908, intrusted by Congress to the care of the Smithsonian Institution, balances of previous appropriations at the beginning of the fiscal year, and amounts unexpended on June 30, 1908:

	Available July 1, 1907.	Balance June 30, 1908.
Smithsonian Institution, balance July 1, 1907	$24,592.01	
Smithsonian Institution, receipts to June 30, 1908	63,372.96	
	87,964.97	$18,766.41
Appropriations committed by Congress to care of the Institution:		
International exchanges, 1906	3.98	[a] 3.98
International exchanges, 1907	2,210.76	.....
International exchanges, 1908	32,000.00	2,667.88
American Ethnology, 1906	9.51	[a] 8.09
American Ethnology, 1907	933.80	10.26
American Ethnology, 1908	40,000.00	947.64
Astrophysical Observatory, 1906	157.26	[a] 61.86
Astrophysical Observatory, 1907	1,937.98	36.50
Astrophysical Observatory, 1908	13,000.00	2,155.35
International Catalogue, 1907	120.94	11.24
International Catalogue, 1908	5,000.00	145.37
Ruin of Casa Grande, 1907	.53	.53
Ruin of Casa Grande, 1908	3,000.00	7.98
National Museum:		
Furniture and fixtures, 1906	410.93	[a] 410.93
Furniture and fixtures, 1907	3,492.34	133.79
Furniture and fixtures, 1908	20,000.00	1,813.83
Heating and lighting, 1906	244.38	[a] 244.38
Heating and lighting, 1907	1,823.80	157.70
Heating and lighting, 1908	18,000.00	1,345.14
Preservation of collections, 1906	1,025.19	[a] 927.48
Preservation of collections, 1907	3,689.81	471.89
Preservation of collections, 1908	190,000.00	4,767.33
Books, 1906	58.69	[a] 53.40
Books, 1907	1,341.70	31.31
Books, 1908	2,000.00	935.01
Postage, 1908	500.00	.....
Building repairs, 1906	105.98	[a] 105.98
Building repairs, 1907	630.54	35.88
Building repairs, 1908	15,000.00	555.90
Rent of workshops, 1906	.08	[a] .08
Rent of workshops, 1907	.08	.08
Rent of workshops, 1908	4,580.00	.08
Printing and binding, 1908	73,500.00	20,814.28
National Zoological Park, 1906	512.80	[a] 50.37
National Zoological Park, 1907	8,253.85	1.82
National Zoological Park, 1908	110,000.00	4,821.57
	641,509.90	

[a] Balance carried June 30, 1908, to the credit of the surplus fund, Treasury Department, under provision of section 3691, Revised Statutes.

Statement of income from the Smithsonian fund and other revenues, accrued and prospective, available during the year ending June 30, 1909.

Balance June 30, 1908	$18,766.41
Interest on fund deposited in the United States Treasury, due July 1, 1908, and January 1, 1909	56,695.00
Interest on West Shore Railroad bonds due July 1, 1908, and January 1, 1909	1,680.00
Exchange repayments, sale of publications, rentals, etc	5,000.00
Total available for year ending June 30, 1909	82,141.41

Respectfully submitted.

J. B. HENDERSON,
ALEXANDER GRAHAM BELL,
JOHN DALZELL,
Executive Committee.

WASHINGTON, D. C.,
December 1, 1908.

PROCEEDINGS OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1908.

At a meeting of the Board of Regents held March 12, 1903, the following resolution was adopted:

Resolved, That, in addition to the prescribed meeting held on the fourth Wednesday in January, regular meetings of the board shall be held on the Tuesday after the first Monday in December and on the 6th day of March, unless that date falls on Sunday, when the following Monday shall be substituted.

At the annual meeting of the board held on January 22, 1908, the above resolution was amended as follows:

Resolved, That hereafter the Board of Regents of the Smithsonian Institution shall hold an annual meeting on the Tuesday after the second Monday in December and another meeting on the second Wednesday in February.

In accordance with the first of these resolutions, the board met at 10 o'clock a. m. on December 3, 1907, and January 22, 1908, and, as provided in the second, on February 12, 1908.

REGULAR MEETING OF DECEMBER 3, 1907.

Present: Mr. Chief Justice Fuller (chancellor) in the chair, Vice-President Charles W. Fairbanks, Senator S. M. Cullom, Senator Henry Cabot Lodge, Senator A. O. Bacon, Representative John Dalzell, Representative James R. Mann, Representative William M. Howard, Dr. Andrew D. White, the Hon. John B. Henderson, and the secretary, Mr. Charles D. Walcott.

ANNUAL REPORT OF THE SECRETARY.

The secretary presented his report on the operations of the Institution for the year ending June 30, 1907, including the report on the National Museum for the same time.

On motion, the report was accepted.

AUDIT OF ACCOUNTS.

The secretary brought up the question of auditing the accounts of the Institution, and after discussion the following resolution was adopted:

Resolved, That hereafter the accounts of the Institution shall be audited annually under the direction of the executive committee.

EMERGENCY SUPERINTENDENT OF CONSTRUCTION.

Referring to the action of the board at the meeting of March 6, 1907, in providing for a continuation of the work on the new building for the National Museum under certain contingencies, the secretary explained that the same necessity existed at the present, and after discussion the following resolution was adopted:

Resolved, That after this date, if the superintendent of construction of the new building for the National Museum, whose services are provided for in the sundry civil act approved March 3, 1903, shall become incapacitated for the performance of his duties when the board is not in session, the secretary of the Institution, subject to the approval of the executive committee, is hereby authorized and directed to personally take charge of the work of construction on behalf of the board and to disburse appropriations made for the same, or appoint some suitable person or persons to take charge of said construction and disburse such appropriations.

ACKNOWLEDGMENTS.

The secretary read a letter from Mr. Francis Peters Adams, brother of the late Representative Robert Adams, jr., a regent of this Institution, acknowledging the action of the board in adopting resolutions on the death of Mr. Adams.

ESTIMATES.

National Gallery of Art.—The secretary read as follows from section 5586 of the act of August 10, 1846, organizing the Institution:

Whenever suitable arrangements can be made from time to time for their reception, all objects of art and of foreign and curious research * * * shall be delivered to such persons as may be authorized by the Board of Regents to receive them.

In this connection he called attention to the following statement of a special committee of the Board of Regents, and to the resolution of the board adopted January 26, 1847 (S. Doc., 29th Cong., 2d sess., No. 211, p. 26):

The gallery of art, your committee think, should include both paintings and sculpture, as well as engravings and architectural designs; and it is desirable to have in connection with it one or more studios in which young artists might copy without interruption, being admitted under such regulations as the board may prescribe. Your committee also think that, as the collection of paintings and sculpture will probably accumulate slowly, the room destined for a gallery of art might properly and usefully meanwhile be occupied during the sessions of Congress as an exhibition room for the works of artists generally; and the extent and general usefulness of such an exhibition might probably be increased if an arrangement could be effected with the Academy of Design, the Arts-Union, the Artists' Fund Society, and other associations of similar character, so as to concentrate at the metropolis for a certain portion of each winter the best results of talent in the fine arts.

Resolved, That it is the intention of the act of Congress establishing the Institution, and in accordance with the design of Mr. Smithson as expressed in his will, that one of the principal modes of executing the act and the trust is the accumulation of

collections of specimens and objects of natural history and of elegant art, and the gradual formation of a library of valuable works pertaining to all departments of human knowledge, to the end that a copious storehouse of materials of science, literature, and art may be provided which shall excite and diffuse the love of learning among men, and shall assist the original investigations and efforts of those who may devote themselves to the pursuit of any branch of knowledge.

The secretary went on to say that the Smithsonian Institution had been known for many years as mainly interested in the development of scientific research, but it had been also interested in art from the very beginning in connection with the museum; the development of the museum had been chiefly along the lines of natural history, geology, and anthropology, because its first thirty years were coincident with the period in which scientific men in the United States were engaged in aiding practical men in the conquest of nature. Even in this period, however, the fine arts, the decorative, and the applied arts had received considerable attention.

The secretary explained that while the administration of the National Gallery could very well be carried on under the present scheme of organization, it was desirable that a special advisory committee of experts be formed to advise him on art matters.

He then called attention to the item in the estimates requesting an appropriation of $60,000 for adapting the large upper hall of the Smithsonian building to the purposes of the National Gallery of Art. He explained that since the March meeting of the board a valuable collection of paintings, fifty-four in number, had been given to the National Gallery by Mr. William T. Evans, of Montclair, N. J.; that within a few days a number of gentlemen in Washington had purchased and presented one of the best paintings of Max Weyl, a local artist of distinction.

It was evident that provision of quarters for the paintings was pressing. The Corcoran Gallery of Art, which had courteously provided space for the exhibition of the Evans collection, required the place so occupied for loan exhibitions, and while the trustees had expressed their willingness to care for this collection until the Institution could make provision for it, it was not desirable that this should be long delayed.

After discussion, the following resolutions were adopted:

Resolved, That the Board of Regents of the Smithsonian Institution bring to the attention of the Congress the urgent need for the provision of quarters for the National Gallery of Art, and earnestly recommend the item of $60,000 submitted by the secretary in the regular estimates for this purpose.

Resolved further, That the secretary be, and he is hereby, instructed to transmit to the chairman of the Committee on Appropriations of the Senate and to the chairman of the Committee on Appropriations of the House of Representatives a copy of these resolutions.

SECRETARY'S STATEMENT.

Request of the British consul-general at Genoa.—At the meeting of the board held January 27, 1892, Secretary Langley reported that, at the suggestion of the authorities of the English cemetery at Genoa, he had deposited with the bankers, Granet, Brown & Co., the sum of 500 Italian lire ($147), the interest on which was to be used for the keeping in order of the grave of James Smithson. As was known to the board, the grounds of the cemetery had been expropriated by the Italian Government, and the remains of Smithson brought to this country and deposited in the Smithsonian Institution.

The British consul-general at Genoa had sent a circular letter to those interested in the British cemetery at Genoa showing that a considerable debt had been incurred in the necessary removal of the graves and chapel, and requesting, in view of the fact that the remains of Smithson lay so long in the cemetery, that the $147 originally deposited be used in whole or in part in paying off the debt of the cemetery which, though British, was open to all Americans.

Under date of March 26, the secretary replied that he did not feel authorized to decide upon the final disposition of the sum named, and promised to lay the matter before the board at this meeting.

Mr. Dalzell then submitted the following resolution, which was adopted:

Resolved, That the Board of Regents of the Smithsonian Institution authorize that the sum of $147, deposited under the approval of the board with the firm of Granet, Brown & Co., in August, 1891, by Secretary Langley, "for the upkeep of Mr. Smithson's grave," be applied to the purposes of the British cemetery in accordance with the request of the British consul-general at Genoa.

The Evans collection.—The secretary called the attention of the board to the gift of the William T. Evans collection of paintings, and stated that the advance made by the National Gallery of Art since the last meeting of the board was briefly outlined on pages 31–33 of his report, and that it would be more fully described in the report of the assistant secretary in charge of the National Museum.

The secretary added that the only conditions or suggestions made by Mr. Evans were that he wished to replace any inferior examples with better ones, and further, that he desired to add to the collection as opportunity offered, as embodied in the following paragraphs of his letter of March 12, 1907, announcing the gift:

"I have every reason to believe that you will like my selections, but should any of the examples not hold up well, others can be substituted, as it is my desire to have every artist represented at his best.

"As already intimated, I intend that the present gift may not be considered as final. Additions may be made from time to time as opportunities occur to secure exceptional works."

After discussion, the following resolution was adopted:

Resolved, That the thanks of the Board of Regents of the Smithsonian Institution be tendered to Mr. William T. Evans, of Montclair, N. J., for the generous gift of his valuable collection of paintings to the National Gallery of Art; that the Regents in accepting the gift recognize his public spirit and devotion to the highest interests of the nation which prompted this splendid donation.

Courtesy of the Corcoran Gallery of Art.—Mr. Evans desired to make an immediate delivery of his collection, but there was no place of sufficient size in the Smithsonian or museum building which could properly accommodate it. In this emergency the Corcoran Gallery of Art courteously extended the use of its large atrium, pending the preparation of a suitable gallery here, and the Secretary thought that the board might wish to formally express its appreciation of this attention.

On motion, the following resolution was adopted:

Resolved, That the thanks of the Board of Regents of the Smithsonian Institution be extended to the trustees of the Corcoran Gallery of Art for their courtesy in providing temporary exhibition space for the William T. Evans donation to the National Gallery of Art.

Hodgkins fund.—The secretary continued: "I have given a good deal of consideration to the use of that portion of the Hodgkins fund devoted to the increase and diffusion of more exact knowledge of the atmospheric air in relation to the welfare of man. While much valuable work has been done under this fund, it seems to me that it would be more in consonance with the ideas of the founder if at least a portion of it might be employed in some way to aid in the knowledge of the prevention of disease and its cure. I am now in consultation with Prof. S. Homer Woodbridge, of the Massachusetts Institute of Technology, sanitary engineer of the new office buildings for the Capitol, Dr. William H. Welch, of Johns Hopkins University, and Dr. Elmer Flick, of the Henry Phipps Institute for the Prevention and Cure of Tuberculosis, at Philadelphia, and hope to be able to initiate some useful investigations along these lines."

Request of the Department of State that the Smithsonian Institution take charge of the United States Government exhibit at the Bordeaux Maritime Exposition.—The secretary stated that the Institution, under the special authority of Congress, has participated for many years in all international expositions at which the Government was represented, but this year for the first time, and in compliance with a request of the Department of State, it has had complete charge of an exhibit for the United States. At the last session Congress passed an appropriation of $15,000 to enable this Government to be represented at Bordeaux. The sum was very small and the time so short that the task seemed impossible, but the secretary was glad to be able to say that through the energetic labors of the museum staff, a display was

installed on July first which not only received high praise from many quarters, but for which a grand prize was awarded.

Research work.—The secretary called attention to the condition of the resources of the Institution, and stated that the balance of the income from the parent fund available July 1, 1908, was too small a sum to initiate any considerable work.

A number of minor investigations were now being carried on by the Institution, which had met the approval of scientific men. Modern research, however, requires a great deal of money, as it must start from the stage of progress of science at the present day, and this often necessitated expensive apparatus, laboratories, and the work of many hands.

If funds can be obtained to be administered under the Smithsonian Institution, the scientific work of the Government can be often supplemented by original researches of a character that would hardly be undertaken by the Government, and which would be of great service to humanity.

DEATH OF WILLIAM J. RHEES.

Mr. William J. Rhees, for many years chief clerk of the Institution, and later keeper of the archives, died on March 18, 1907. Reference to the demise of this faithful official will be found in the annual report. A clause in his will bequeathed $500 to the Institution.

ANNUAL MEETING OF JANUARY 22, 1908.

Present: Mr. Chief Justice Fuller (chancellor) in the chair; Representative John Dalzell, Representative James R. Mann, Representative William M. Howard, Dr. James B. Angell, the Hon. John B. Henderson, Dr. Alexander Graham Bell, the Hon. George Gray, and the secretary, Mr. Charles D. Walcott.

REAPPOINTMENT OF REGENTS.

The chancellor announced the following reappointments of Regents under the terms of section 5581 of the Revised Statutes:

By the President of the Senate, on January 14, 1908, Senator Bacon, of Georgia.

By the Speaker of the House, on December 9, 1907, Representatives Dalzell, Mann, and Howard.

RESIGNATION OF REGENT.

The chancellor submitted the resignation of the Hon. Richard Olney as a Regent, and on motion the following resolution was adopted:

Resolved, That the secretary of the Institution acknowledge the receipt of the telegram from Mr. Richard Olney, tendering his resignation as a Regent of the Smith-

sonian Institution, and express to him the high appreciation of the members of the board of his services as a Regent, and their regret at the termination of his official connection with the Institution.

The secretary was instructed to transmit notice of the resignation to Congress.

RESOLUTION RELATIVE TO INCOME AND EXPENDITURE.

Mr. Henderson, as chairman of the executive committee, submitted the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1909, be appropriated for the service of the Institution, to be expended by the secretary, with the advice of the executive committee, with full discretion on the part of the secretary as to items.

ANNUAL REPORT OF EXECUTIVE COMMITTEE.

Mr. Henderson, as chairman, presented the annual report of the executive committee for the fiscal year ending June 30, 1907.

On motion, the report was adopted.

ANNUAL REPORT OF THE PERMANENT COMMITTEE.

The permanent committee respectfully submits the following report covering the period since the annual meeting of the Board of Regents on January 23, 1907:

Hodgkins estate.—As reported to the board by the secretary, at its meeting on March 6, 1907, the government bonds constituting the residuum of the estate of the late Thomas George Hodgkins, and held by the New York Life and Trust Company pending the final decision, on appeal, of a suit in which the liability of the estate of Mr. Hodgkins on a warranty of title by him in the transfer of certain real property in New York City was in question, were, in accordance with a resolution by the Board of Regents, sold and the proceeds deposited to the credit of the permanent Smithsonian Fund in the United States Treasury. No other transactions occurred during the year with reference to the funds received by the Institution through the Hodgkins bequest.

Andrews estate.—The hearing on appeal from the decision of the supreme court of New York City, in May, 1906, sustaining the bequest of Mr. Wallace C. Andrews for the establishment of the Andrews Institute for Girls, at Willoughby, Ohio, took place at Albany, N. Y., on January 15, 1908, the Institution being represented by Mr. Frank W. Hackett and Mr. Edmund Wetmore. It was argued by counsel for the Institution that the Smithsonian does not wish to receive the legacy involved, unless in so doing it is carrying out the wishes of Mr. Andrews in the matter. The sum involved, as has been already stated to the board, is estimated at more than a million and a half dollars.

Avery estate.—The Institution is still in possession of four parcels of real estate, to which it received title by the bequest of the late Robert Stanton Avery. The recent improvements in their vicinity have greatly enhanced the value of these properties.

Sprague and Reid bequests.—As has been previously reported to the board, the residual legacies to the Institution under the terms of the Sprague and Reid bequests are subject to the death of certain enumerated legatees, and it is probable that the Institution will not derive any actual income from these estates for some years to come.

J. B. HENDERSON,
Chairman Permanent Committee,
Board of Regents, Smithsonian Institution.

On motion, the report was accepted.

ACKNOWLEDGMENT OF BRITISH CONSUL-GENERAL AT GENOA.

The secretary brought before the board a letter from the British consul-general at Genoa, conveying the thanks of the British cemetery authorities for the action of the board taken at the meeting of December 3, 1907, in placing the sum of $147 at their disposal for the purposes of the cemetery.

SECRETARY'S STATEMENT.

Committee on National Gallery of Art.—"In accordance with the view discussed at the meeting on December 3, 1907, and as the result of various conferences held in Washington and New York, I have come to the conclusion that at the outset it is advisable to create an advisory committee for the National Gallery of Art, composed of five persons, two of whom shall be nominated by the Institution and the other three shall be chosen by the National Academy of Design, the National Sculpture Society, and the Fine Arts Federation, respectively. This last organization is itself a representative body composed of delegates from all of the art societies in New York. Of the two members named by the Institution, one, I think, should be resident in Washington and the other should be an appointment at large, as it were, a man who represents all art interests and is acceptable to all.

"It is my opinion that this committee should not be a permanent one; that the members should hold their appointments for a period of three years, and possibly not be eligible to immediate reappointment, and that it should be so arranged that, say, no more than two would leave the committee in any one year.

"I am satisfied that as a result of the conferences valuable advice can be secured from the most eminent persons in this country, and that this scheme will acceptably bridge over the time until a proper

staff can be secured and maintained. This plan is not new with the Institution, as from the beginning the secretary has been advised by committees, a majority of which were generally persons not connected with the Institution.

"It is also my opinion that if the Institution takes this step now it will be of importance not simply for the Institution itself, but for the art interests of the entire nation, and that it will have its influence in setting a proper standard of judgment and criticism in art matters."

The new building for the National Museum.—Since the last meeting of the board the outer walls of this building have been entirely completed, except at the south or main pavilion, where they have been carried slightly above the level of the second-story floor. The delay at this place has been mainly caused by the failure of the quarry to furnish stone as rapidly as required, but it does not interfere with work elsewhere on the building, which, for some time, has been progressing rapidly and satisfactorily.

After careful consideration of all that remains to be done, there seems no reason to doubt that if there are no unforeseen interruptions the building will be ready for occupancy by January next, as was predicted some time ago by the superintendent of construction.

Expedition to observe a total eclipse of the sun.—Mr. C. G. Abbot, the director of the Astrophysical Observatory, was sent on an expedition in conjunction with Professor Campbell, director of Lick Observatory, to Flint Island in the South Pacific, about 400 miles north of Tahiti, to observe a total eclipse of the sun occurring January 3, 1908.

It has been impossible for Mr. Abbot to make a full report as yet, but cablegrams received indicate that he has had a most successful expedition, the results of which will be communicated to the board later.

Publicity bureau.—The secretary stated that in accordance with his suggestion at the meeting on March 6, 1907, the articles published by the Institution had been put in popular form and sent to a number of newspapers for the wider dissemination than could be afforded in the formal reports. As a result the activities of the Institution had been brought to public notice to a greater extent than heretofore; and it was felt that one of the functions of the Institution, the "diffusion" of knowledge, was being enlarged and satisfactorily complied with.

Meetings of the Board of Regents.—The secretary brought up the matter of a change in the dates of the board meetings, and after explanation and discussion, the following resolution was adopted:

Resolved, That hereafter the Board of Regents of the Smithsonian Institution shall hold an annual meeting on the Tuesday after the second Monday in December and another meeting on the second Wednesday in February.

Casa Grande, Arizona.—Dr. J. W. Fewkes, of the Bureau of American Ethnology, who has had wide experience as an archeologist, spent last winter in the excavation and restoration of the first group of remarkable ruins at Casa Grande, Arizona, under the appropriation made to the Institution for that purpose.

Doctor Fewkes is now at Casa Grande investigating the second group or "compound" of these ruins, and his reports indicate that much valuable information regarding the aborigines of this section will be obtained from the investigations now in progress.

Mesa Verde National Park, Colorado.—At the request of the Secretary of the Interior, Doctor Fewkes was directed on October 31, 1907, upon the completion of the season's work at Casa Grande, to assume charge of the excavation, preservation, and repairs of the cliff dwellings and other prehistoric ruins in the Mesa Verde National Park, which has recently been set aside by the President as a national park on account of the important ruins it contains.

In reply to a question the secretary explained the provisions of the law for the preservation of American antiquities, which was intended to prevent the destruction and waste of antiquities by unauthorized persons or organizations, and cited several instances of such depredations.

REGULAR MEETING OF FEBRUARY 12, 1908.

Present, Mr. Chief Justice Fuller (chancellor) in the chair; Representative James R. Mann, Representative William M. Howard, Dr. A. Graham Bell, and the Secretary, Mr. Charles D. Walcott.

Adjournment.—There being no quorum present, the chancellor declared the meeting adjourned, previous to which, however, there was an informal discussion on matters in connection with the Institution and its branches.

ACTS AND RESOLUTIONS OF CONGRESS RELATIVE TO THE SMITHSONIAN INSTITUTION, ETC.

[Continued from previous reports.]

[Sixtieth Congress, first session.]

SMITHSONIAN INSTITUTION.

APPOINTMENT OF REGENT: *Resolved by the Senate and House of Representatives of the United States of America in Congress assembled*, That the vacancy in the Board of Regents of the Smithsonian Institution of the class "other than Members of Congress" shall be filled by the appointment of Charles F. Choate, junior, a citizen of Massachusetts. (Approved, February 24, 1908; Statutes, XXXV, 567.)

SMITHSONIAN GROUNDS: For improvement, care, and maintenance of Smithsonian grounds, three thousand dollars. (Approved, May 27, 1908; Statutes, XXXV, 355.)

PRINTING AND BINDING: For the Smithsonian Institution, for printing and binding the Annual Reports of the Board of Regents, with general appendixes, ten thousand dollars; under the Smithsonian Institution, for the Annual Reports of the National Museum, with general appendixes, and for printing labels and blanks, and for the Bulletins and Proceedings of the National Museum, the editions of which shall not exceed four thousand copies, and binding, in half turkey or material not more expensive, scientific books and pamphlets presented to and acquired by the National Museum Library, thirty-four thousand dollars; for the Annual Reports and Bulletins of the Bureau of American Ethnology, and for miscellaneous printing and binding for the Bureau, twenty-one thousand dollars; for miscellaneous printing and binding for the International Exchanges, two hundred dollars; the International Catalogue of Scientific Literature, one hundred dollars; the National Zoological Park, two hundred dollars; the Astrophysical Observatory, one hundred dollars; and for the Annual Report of the American Historical Association, seven thousand dollars; in all, seventy-two thousand six hundred dollars. (Approved, May 27, 1908; Statutes, XXXV, 383.)

SMITHSONIAN DEPOSIT (LIBRARY OF CONGRESS): For custodian, one thousand five hundred dollars; assistant, one thousand four hundred dollars; messenger, seven hundred and twenty dollars; messenger boy, three hundred and sixty dollars; in all, three thousand nine hundred and eighty dollars. (Approved, May 22, 1908; Statutes, XXXV, 194.)

WASHINGTON STATUE: *Resolved by the Senate and House of Representatives of the United States of America in Congress assembled*, That the statue of President Washington, now located in the Capitol grounds east of the Capitol, be, and the same is hereby, transferred to the custody of the Smithsonian Institution. (Approved, May 22, 1908; Statutes, XXXV, 576.)

For the transfer of the marble statue of Washington, by Greenough, from the plaza in front of the Capitol to the Smithsonian Institution, under the direction of the Secretary of the Smithsonian Institution and the Superintendent of the Capitol Building and Grounds, including the construction of a foundation and a marble base, five thousand dollars. (Approved, May 30, 1908; Statutes, XXXV, 492.)

PATENT MODELS: For rent of rooms in the Union Building for Patent Office model exhibit during so much of the fiscal year nineteen hundred and nine as may be necessary, and for necessary expenses of removal and storage of said exhibit, nineteen thousand five hundred dollars: *Provided*, That a commission, which is hereby created, to consist of the Secretary of the Interior, the Commissioner of Patents, and the Secretary of the Smithsonian Institution, shall determine which of the models of the Patent Office may be of possible benefit to patentees or of historical value, such models thus selected to be cared for in the new National Museum building, the remainder of said models shall before January first, nineteen hundred and nine, be disposed of by sale, gift, or otherwise as the Commissioner of Patents, with the approval of the Secretary of the Interior, shall determine. (Approved, May 22, 1908; Statutes, XXXV, 229.)

INTERNATIONAL EXCHANGES.

For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, and the purchase of necessary books and periodicals, thirty-two thousand dollars. (Approved, May 27, 1908; Statutes, XXXV, 323.)

NAVAL OBSERVATORY: For repairs to buildings, fixtures, and fences, furniture, gas, chemicals, and stationery, freight (including transmission of public documents through the Smithsonian exchange), foreign postage, and expressage, plants, fertilizers, and all contingent expenses, three thousand dollars. (Approved, May 22, 1908; Statutes, XXXV, 221.)

For repairs to buildings, fixtures, and fences; furniture, gas chemicals, and stationery; freight (including the transmission of public documents through the Smithsonian exchange), foreign postage, and expressage; plants, fertilizer, and all contingent expenses, three hundred dollars. (Approved, May 30, 1908; Statutes, XXXV, 500.)

BUREAU OF AMERICAN ETHNOLOGY.

For continuing ethnological researches among the American Indians and the natives of Hawaii under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees and the purchase of necessary books and periodicals, forty-two thousand dollars, of which sum not exceeding one thousand five hundred dollars may be used for rent of building. (Approved May 27, 1908; Statutes, XXXV, 323.)

ASTROPHYSICAL OBSERVATORY.

For maintenance of Astrophysical Observatory, under the direction of the Smithsonian Institution, including salaries of assistants, the purchase of necessary books and periodicals, apparatus, making necessary observations in high altitudes, repairs and alterations of buildings, and miscellaneous expenses, thirteen thousand dollars. (Approved May 27, 1908; Statutes, XXXV, 324.)

INTERNATIONAL CATALOGUE OF SCIENTIFIC LITERATURE.

For the cooperation of the United States in the work of the International Catalogue of Scientific Literature, including the preparation of a classified index catalogue of American scientific publications for incorporation in the International Catalogue, the expense of clerk hire, the purchase of necessary books and periodicals, and other necessary incidental expenses, five thousand dollars, the same to be expended under the direction of the Smithsonian Institution. (Approved May 27, 1908; Statutes, XXXV, 323.)

NATIONAL MUSEUM.

For cases, furniture, fixtures, and appliances required for the exhibition and safe-keeping of the collections of the National Museum, including salaries or compensation of all necessary employees, fifty thousand dollars.

For expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum, twenty-two thousand dollars.

For continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees, and all other necessary expenses, one hundred and ninety thousand dollars, of which sum five thousand five hundred dollars may be used for necessary drawings and illustrations for publications of the National Museum.

For purchase of books, pamphlets, and periodicals for reference in the National Museum, two thousand dollars.

For repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material, fifteen thousand dollars.

For rent of workshops and temporary storage quarters for the National Museum, four thousand five hundred and eighty dollars.

For postage stamps and foreign postal cards for the National Museum, five hundred dollars.

(Approved May 27, 1908; Statutes, XXXV, 324.)

NATIONAL ZOOLOGICAL PARK.

For continuing the construction of roads, walks, bridges, water supply, sewerage, and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals; including salaries or compensation of all necessary employees, and general incidental expenses not otherwise provided for, including purchase, maintenance, and driving of horses and vehicles required for official purposes, ninety-five thousand dollars, one half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States. (Approved May 27, 1908; Statutes, XXXV, 324.)

For defraying the expenses for witness fees, court costs, professional services of physicians, and other necessary charges incurred in the defense of the suit by Hannah Jackson against Frank Baker, superintendent of the park, one hundred and fifteen dollars and seventy cents. (Approved May 30, 1908; Statutes, XXXV, 492.)

PROTECTION OF ALASKAN GAME.

* * * * * * *

SEC. 6. That it shall be unlawful for any persons, firm, or corporation, or their officers or agents, to deliver to any common carrier, or for the owner, agent,

or master of any vessel, or for any other person, to receive for shipment or have in possession with intent to ship out of Alaska, any wild birds, except eagles, or parts thereof, or any heads, hides, or carcasses of brown bear, caribou, deer, moose, mountain sheep, or mountain goats, or parts thereof, unless said heads, hides, or carcasses are accompanied by the required license or coupon and by a copy of the affidavit required by section five of this act: *Provided*, That nothing in this act shall be construed to prevent the collection of specimens for scientific purposes, the capture or shipment of live animals and birds for exhibition or propagation, or the export from Alaska of specimens under permit from the Secretary of Agriculture, and under such restrictions and limitations as he may prescribe and publish.

"It shall be the duty of the collector of customs at Seattle, Portland, and San Francisco to keep strict account of all consignments of game animals received from Alaska, and no consignment of game shall be entered until due notice thereof has been received from the governor of Alaska or the Secretary of Agriculture, and found to agree with the name and address on the shipment. In case consignments arrive without licenses they shall be detained for sixty days, and if a license be not then produced said consignments shall be forfeited to the United States and shall be delivered by the collector of customs to the United States marshal of the district for such disposition as the court may direct.

* * * * * * *

(Approved May 11, 1908; Statutes, XXXV, 104.)

NATIONAL ACADEMY OF SCIENCES.

The National Academy of Sciences is required, at their next meeting, to take into consideration the methods and expenses of conducting all surveys of a scientific character, and all chemical, testing, and experimental laboratories and to report to Congress as soon thereafter as may be practicable a plan for consolidating such surveys, chemical, testing, and experimental laboratories so as to effectually prevent duplication of work and reduce expenditures without detriment to the public service.

It is the judgment of Congress that any person who holds employment under the United States or who is employed by and receives a regular salary from any scientific bureau or institution that is required to report to Congress should refrain from participation in the deliberations of said National Academy of Science on this subject and from voting on or joining in any recommendaton hereunder. (Approved May 27, 1908; Statutes, XXXV, 387.)

FIRST PAN-AMERICAN SCIENTIFIC CONGRESS, SANTIAGO, CHILE.

To enable the Government of the United States to be fittingly represented at the first Pan-American Scientific Congress to be held at Santiago, Chile, during the year nineteen hundred and eight, thirty-five thousand dollars, to be immediately available and to be expended under the direction of the Secretary of State. (Approved May 27, 1908; Statutes, XXXV, 380.)

INTERNATIONAL CONGRESS ON TUBERCULOSIS.

To enable the Government of the United States suitably to participate in the International Congress on Tuberculosis, which will convene at Washington, September twenty-first to October twelfth, nineteen hundred and eight, twenty-five thousand dollars. (Approved, May 21, 1908; Statutes XXXV, 179.)

Whereas an International Congress on Tuberculosis will meet in Washington in September, nineteen hundred and eight, the same being the Sixth International Congress on Tuberculosis, and the first to be held in America; and

Whereas seven of the nine departments of the Federal Government have petitioned Congress for the authority and means to participate in this Congress; and

Whereas the governors of twenty-eight States of the United States have authorized the participation of their several States in this Congress; and

Whereas the National Association for the Study and Prevention of Tuberculosis has provided the necessary means and created a special committee to secure the participation of voluntary and private interests in the coming International Congress on Tuberculosis; and

Whereas preceding International Congresses occurring in other countries in the past fifteen years have been held under governmental auspices, and delegates from the United States have participated therein as guests of foreign governments: Therefore be it

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That the Department of State be, and is hereby, authorized to invite the governments of other countries, through their ministers, to send representatives to the International Congress on Tuberculosis, to be held in Washington, September twenty-first to October twelfth, nineteen hundred and eight. (Approved, March 6, 1908; Statutes, XXXV, 568.)

That the President be, and he is hereby, empowered and requested to direct the Secretary of the Smithsonian Institution and the Secretary of Agriculture to place at the disposition of the International Tuberculosis Congress, under such terms and conditions as the President may authorize or prescribe, such space, not now occupied, in the new National Museum and Agricultural buildings, respectively, as may be needed to properly provide for the meeting of such International Tuberculosis Congress, including exhibits, to be held in September and October of the present year, and the use of said buildings for such purposes is hereby authorized; and permanent occupancy of such buildings, respectively, shall be postponed in so far as may be necessary to carry out the foregoing provisions; and the sum of forty thousand dollars, or so much thereof as may be necessary, to be expended in accordance with the directions of the President for the payment of expenses in connection with the suitable temporary preparation of said buildings for such purposes, is hereby appropriated. (Approved, May 30, 1908; Statutes XXXV, 479.)

EXPOSITION AT QUITO, ECUADOR.

For the participation by the United States in an exposition to be held at Quito, Ecuador, during the year nineteen hundred and nine, the sending of a commissioner to the same, a Government exhibit, the necessary expenses of transportation, and the erection of a building at the exposition, fifty thousand dollars, or so much thereof as may be necessary, to be expended under the direction of the Secretary of State. (Approved, May 27, 1908; Statutes XXXV, 380.)

ALASKAN-YUKON-PACIFIC EXPOSITION, SEATTLE, WASHINGTON.

* * * * * * *

SEC. 11. That there shall be exhibited at said exposition by the Government of the United States from the Smithsonian Institution and the National Museum such articles and material of an historical nature as will impart a knowledge

of our national history, especially that of Alaska, Hawaii, and the Philippine Islands and that part of the United States west of the Rocky Mountains. There shall be exhibited from the executive departments of the United States such exhibits as will illustrate their principal administrative functions and their educational value in connection with the development of commerce in the countries bordering upon the Pacific Ocean; the preservation of forests; the reclamation and irrigation of arid and semiarid lands; the improving and enlarging of transportation facilities and the safeguards of navigation; and the economic value of the investigations and operations of the Government with reference to public health, geology, experiment stations, coast and geodetic survey, and public roads. To secure a complete and harmonious arrangement of such government exhibit a United States Government board of managers is hereby authorized to be appointed to be charged with the selection, purchase, preparation, transportation, arrangement, safe-keeping, exhibition and return of such articles and materials as the heads of the several departments, the Secretary of the Smithsonian Institution, the Superintendent of the National Museum, respectively, decide shall be embraced in the government exhibit herein authorized. The President of the United States may also designate additional articles of peculiar interest for exhibition in connection with the said government exhibit. Said government board of managers shall be composed of three persons now in the employ of the Government, and shall be appointed by the President, one of whom shall be designated by the President as chairman of the said board and one as secretary and disbursing officer. The members of said government board, with other officers and employees of the Government who may be detailed to assist them, including officers of the army and navy, shall receive no compensation in addition to their regular salaries, but they shall be allowed their actual and necessary traveling expenses, together with a per diem in lieu of subsistence, to be fixed by the Secretary of the Treasury, while necessarily absent from their homes engaged upon the business of the board. Officers of the army and navy shall receive said allowance in lieu of the subsistence and mileage now allowed by law; and the Secretary of War and the Secretary of the Navy may, in their discretion, detail retired army and navy officers for such duty. Any provision of law which may prohibit the detail of persons in the employ of the United States to other service than that which they customarily perform shall not apply to persons detailed for duty in connection with said Alaska-Yukon-Pacific Exposition. Employees of the board not otherwise employed by the Government shall be entitled to such compensation as the board may determine, and such employees may be selected and appointed by said board. The disbursing officer shall give bond in such sum as the Secretary of the Treasury may determine for the faithful performance of his duties, said bond to be approved by said Secretary. The Secretary of the Treasury shall advance to said officer from time to time, under such regulations as he may prescribe, a sum of money from the appropriation for the government exhibit herein authorized, not exceeding at any one time three-fourths of the penalty of his bond, to enable him to pay the expenses of said exhibit as authorized by the United States Government board herein created. The Secretary of the Treasury is hereby authorized and directed to place on exhibition, in connection with the exhibit of his department, upon such grounds as shall be allotted for this purpose, one of the life-saving stations authorized to be constructed on the Pacific Coast of the United States by existing law, and to cause the same to be fully equipped with all apparatus, furniture, and appliances now in use in life-saving stations in the United States. The Secretary of Commerce and Labor is hereby authorized and

directed to place on exhibition, in connection with the exhibit of his department, in such building or aquarium as shall be allotted for this purpose, a complete exhibit of the fish and fisheries of the United States, paying special attention to the fish and fisheries of the Pacific Ocean, with a view to demonstrating, in the fullest manner possible, the economic value of such fish and fisheries: *Provided*, That the cost of said exhibit herein authorized, including the selection, purchase, preparation, transportation, arrangement, safe-keeping, exhibition, and return of the articles and materials so exhibited, shall not exceed the sum of two hundred thousand dollars, which sum, or so much thereof as may be necessary, is hereby appropriated out of any money in the Treasury not otherwise appropriated.

* * * * * * *

SEC. 14. That the Secretary of the Treasury shall cause suitable buildings to be erected on the site of said Alaska-Yukon-Pacific Exposition for said government exhibit, including an irrigation and biograph building; also a fisheries building complete, with mechanical apparatus; also buildings for the exhibits of the district of Alaska, the Territory of Hawaii, and the Philippine Islands; also buildings for such other purposes in connection with the exhibits herein authorized as in the judgment of the Secretary of the Treasury may be necessary. Said buildings shall be erected from plans prepared by the Supervising Architect of the Treasury, to be approved by the Secretary of the Treasury, and the Secretary of the Treasury is hereby authorized and directed to contract for said buildings in the same manner and under the same regulations as for other public buildings of the United States, but the contract for said buildings, including the preparation of ground therefor and the approaches thereto, and the interior and exterior decorative wiring and lighting thereof shall not exceed the sum of two hundred and fifty thousand dollars, which sum, or so much thereof as may be necessary, is hereby appropriated out of any money in the Treasury not otherwise appropriated. The Secretary of the Treasury is authorized and required to dispose of said buildings, or the materials composing the same, at the close of the exposition, giving preference to the State of Washington or to the Alaska-Yukon Pacific Exposition corporation or to the city of Seattle to purchase the same at an appraised value to be ascertained in such manner as the Secretary of the Treasury may determine.

* * * * * * *

SEC. 17. That the United States shall not be liable on account of said exposition for any expenses incident to or growing out of the same, except for the construction of the building or buildings hereinbefore authorized and for the purpose of paying the expense incident to the selection, preparation, purchase, installation, transportation, care, custody, and safe return of the exhibits made by the Government and for the employment of proper persons as officers and assistants by the government board created by this act, and for other expenses, and for the maintenance of said building or buildings and other contingent expenses to be approved by the chairman of the government board, or, in the event of his absence or disability, by such officer as the board may designate, and the Secretary of the Treasury, upon itemized accounts and vouchers.

* * * * * * *

SEC. 19. That nothing in this act shall be construed so as to create any liability upon the part of the United States, directly or indirectly, for any debt or obligation incurred or for any claim for aid or pecuniary assistance from Congress or the Treasury of the United States in support or liquidation of any debts or obligations created by said United States Government board in excess of appropriations herein made.

(Sundry civil act, approved May 27, 1908; Statutes, XXXV, 388–391.)

GREAT NATIONAL EXPOSITION, TOKYO, JAPAN.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That the President be, and he is hereby, authorized to accept the invitation extended by the Imperial Japanese Government to the Government of the United States to participate in the Great National Exposition to be held in Tokyo, Japan, from April first to October thirty-first, nineteen hundred and twelve. In accepting said invitation it is hereby declared to be the purpose of the Government of the United States to participate in said Japanese National Exposition by erecting suitable buildings and making an appropriate exhibit of arts, industries, manufactures, and products of the soil and mines and as far as practicable of the functions of the General Government of the United States and an exhibit of such other articles as the President of the United States may direct: *Provided*, That such participation, buildings, exhibits, and all expenses connected therewith, including salaries, clerical, and other services and transportation of persons and exhibits shall not exceed one million five hundred thousand dollars.

SEC. 2. That the President be, and he is hereby, authorized, by and with the advice and consent of the Senate, to appoint three commissioners-general who shall, under the direction of the Secretary of State, take such steps as are necessary to ascertain the general plan and scope of the said National Exposition, the character, size, and cost of the buildings to be erected by the United States, and the extent and character of the exhibit authorized hereunder that would best serve the interests of the United States and its citizens, and would be best adapted to illustrate the growth and development of the country and the character of our people. That thereafter, and as soon as practicable, said commissioners shall report fully to the President and to Congress the result of such investigation, together with their recommendations and the estimated cost of said participation in said exposition, within the foregoing authorization; and it shall also be the duty of the commissioners-general to report to the President for transmission to Congress at the beginning of each regular session a detailed statement of all expenditures incurred hereunder. That one of said commissioners-general shall receive as compensation for his services the sum of eight thousand dollars per annum; that the other two commissioners-general shall receive as compensation for their services from and after January first, nineteen hundred and nine, two thousand dollars per annum for the first year and five thousand dollars per annum thereafter, together with the actual traveling expenses of all of said commissioners-general, including sleeping-car service and a per diem in lieu of subsistence of five dollars when actually traveling in the discharge of their duties as said commissioners-general. That the President shall also appoint a secretary at a compensation of five thousand dollars per annum, together with his actual traveling expenses, including sleeping-car service and a per diem in lieu of subsistence of five dollars when actually traveling in the discharge of his duties as such secretary, who shall act as disbursing agent and who shall perform such duties as may be assigned to him from time to time by the commissioners-general, and who shall render his accounts at least quarterly to the proper accounting officers of the Treasury of the United States, and shall give bond in such sum as the Secretary of the Treasury may require. And the said commissioners-general, subject to the approval of the Secretary of State, shall appoint from time to time such clerical and other assistants as may be necessary and as may hereafter be appropriated for in connection with the preparation of the plan and other necessary services as may be required in connection with the participation herein authorized.

SEC. 3. That upon the request of the Secretary of State the Secretary of War is hereby authorized to furnish free transportation on government transports from San Francisco to Japan and return of all government exhibits and for such officials or employees connected with the commission or in charge of any or all government exhibits.

SEC. 4. That the sum of fifty thousand dollars is hereby appropriated, out of any money in the Treasury not otherwise appropriated, for the purpose of paying the salaries and all other expenses herein authorized and incurred in ascertaining the general plan of said National Exposition and the preparation and report to Congress of the plan and extent of our proposed participation therein and the estimate of the amount necessary to meet the expense thereof during the fiscal year nineteen hundred and ten, to be immediately available.

(Approved, May 22, 1908; Statutes, XXXV, 183.)

STATEMENT OF TRAVEL ON OFFICIAL BUSINESS.

SEC. 4. It shall be the duty of the head of each executive department and other government establishment at Washington to submit to Congress at the beginning of each regular session a statement showing in detail what officers or employees (other than special agents, inspectors, or employees, who in the discharge of their regular duties are required to constantly travel) of such executive department or other government establishment have traveled on official business from Washington to points outside of the District of Columbia during the preceding fiscal year, giving in each case the full title of the official or employee, the destination or destinations of such travel, the business or work on account of which the same was made, and the total expense to the United States charged in each case. (Approved, May 22, 1908; Statutes XXXV, 244.)

AMENDING ACT RELATING TO PUBLIC PRINTING AND BINDING.

Resolved by the Senate and House of Representatives of the United States of America in Congress assembled, That publications ordered printed by Congress, or either House thereof, shall be in four series, namely: One series of reports made by the committees of the Senate, to be known as Senate reports; one series of reports made by the committees of the House of Representatives, to be known as House reports; one series of documents other than reports of committees, the orders for printing which originate in the Senate, to be known as Senate documents, and one series of documents other than committee reports, the orders for printing which originate in the House of Representatives, to be known as House documents. The publications in each series shall be consecutively numbered, the numbers in each series continuing in unbroken sequence throughout the entire term of a Congress, but the foregoing provisions shall not apply to the documents printed for the use of the Senate in executive session: *Provided*, That of the "usual number," the copies which are intended for distribution to state and territorial libraries and other designated depositories of all annual or serial publications originating in or prepared by an executive department, bureau, office, commission, or board shall not be numbered in the document or report series of either House of Congress, but shall be designated by title and bound as hereinafter provided, and the departmental edition, if any, shall be printed concurrently with the "usual number:" *And provided further*, That hearings of committees may be printed as congressional documents only when specifically ordered by Congress or either House thereof.

SEC. 2. That in the binding of congressional documents and reports for distribution by the superintendent of documents to state and territorial libraries and other designated depositories, every publication of sufficient size on any one subject shall hereafter be bound separately and receive the title suggested by the subject of the volume, and the others shall be distributed in unbound form as soon as printed. The Public Printer shall supply the superintendent of documents sufficient copies of those publications distributed in unbound form, to be bound and distributed to the state and territorial libraries and other designated depositories for their permanent files. The library edition, as well as all other bound sets of congressional numbered documents and reports, shall be arranged in volumes and bound in the manner directed by the Joint Committee on Printing.

SEC. 3. That section two of an act to amend an act providing for the public printing and binding, and so forth, approved March first, nineteen hundred and seven, is hereby repealed.

(Approved January 15, 1908; Statutes, XXXV, 566.)

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1908

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the secretary, induced in part by the discontinuance of an annual summary of progress which for thirty years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1908.

THE PRESENT STATUS OF MILITARY AERONAUTICS.[a]

[With 23 plates.]

By Dr. George O. Squier,[b]
Major, Signal Corps, U. S. Army.

It is a matter of first significance that The American Society of Mechanical Engineers, composed of a body of highly trained and serious-minded men, should be considering in annual meeting assembled the subject of aerial navigation. Five years ago such a subject could scarcely have had a place on the list of professional papers on your programme. The present period will ever be memorable in the history of the world for the first public demonstrations of the practicability of mechanical flight. In fact, at the present moment a resistless wave of enthusiasm and endeavor, sweeping away every prejudice, is passing over the entire civilized world, fixing the attention of all classes upon the problem of flight. France, Germany, and England are in a state of frenzied interest in this subject, and each period of a single month sees some new step accomplished in the march of progress. The universal highway is at last to be made available for the uses of mankind, with its consequent influence upon our modes of life and thought. * * *

There are two general classes of vehicles of the air, (*a*) those which depend for their support upon the buoyancy of some gas lighter than air, and (*b*) those which depend for such support upon the dynamic reaction of the air itself. These classes are designated—

(*a*) Lighter-than-air types: Free balloons, dirigible balloons or airships.

(*b*) Heavier-than-air types: Aeroplanes, orthopters, helicopters, etc.

It should be remarked, however, that these two general classes exhibit a growing tendency to overlap each other. For example, the latest dirigible balloons are partly operated by means of aeroplane

[a] Reprinted by permission (abridged by author) from the Journal of The American Society of Mechanical Engineers, New York, 1909, pp. 1571-1612.

[b] Presented at the New York meeting (December, 1908) of The American Society of Mechanical Engineers.

surfaces, and are also often balanced so as to be slightly heavier than the air in which they move, employing the propeller thrust and rudder surfaces to control the altitude.

I. Aerostation.

Captive and free balloons, with the necessary apparatus and devices for operating the same, have been for many years considered an essential part of the military establishment of every first-class power. They played a conspicuous part in the siege of Paris, and were often valuable in our own civil war. The construction and operation of aerostats are too well understood to need further attention here.

Successful military dirigible balloons.

France.

Two types of dirigible balloons have been used in the French army—first, the Patrie, and, second, the Ville de Paris.

The Patrie was developed by Julliot, an engineer employed by the Lebaudy Brothers at their sugar refinery in Paris. A history of his work beginning in 1896 is fully given in La Conquête de l'Air.

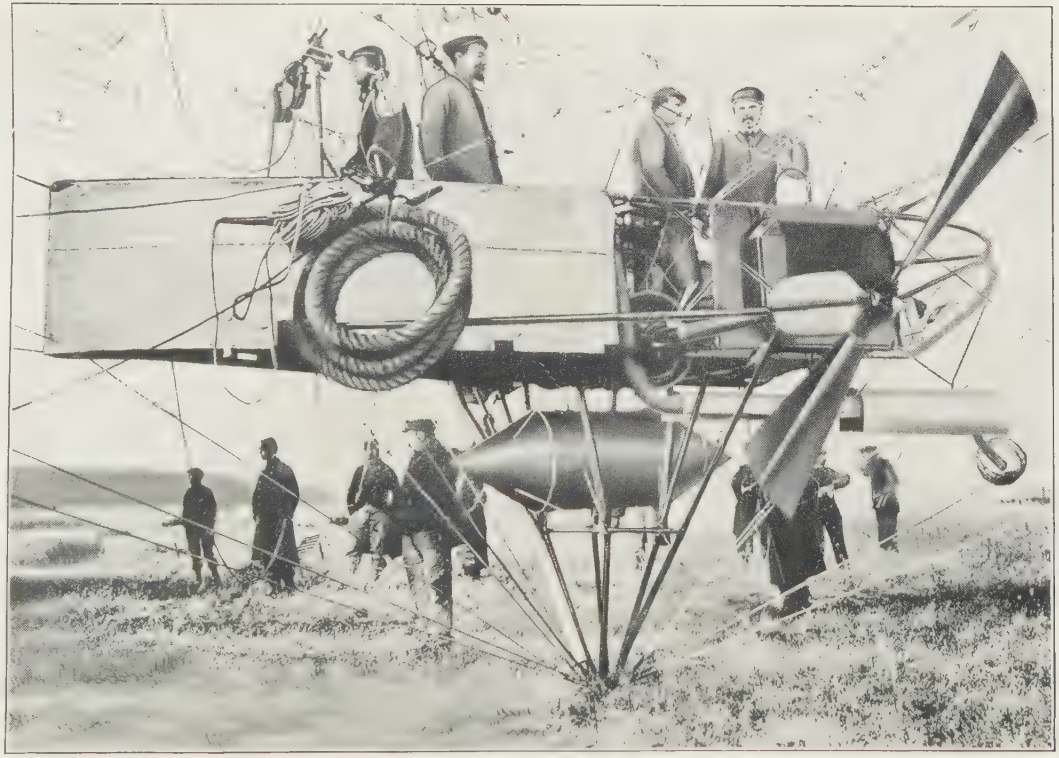
The Patrie.

The Patrie, the third of its type, was first operated in 1906. The gas bag of the first balloon was built by Surcouf at Billancourt, Paris. The mechanical part was built at the Lebaudy sugar refinery. Since then the gas bags have been built at the Lebaudy balloon shed at Moisson, near Paris, under the direction of their aeronaut, Juchmés. The gas bag of the Patrie was 197 feet long, with a maximum diameter of 33 feet 9 inches, situated about two-fifths of the length from the front; volume, 111,250 cubic feet; length, approximately six diameters. This relation, together with the cigar shape, is in accordance with the plans of Colonel Renard's dirigible, built and operated in France in 1884; the same general shape and proportions being found in the Ville de Paris.

The first Lebaudy was pointed at the rear, which is generally admitted to be the proper shape for the least resistance, but to maintain stability it was found necessary to put a horizontal and vertical plane there, so that it had to be made an ellipsoid of revolution to give attachment for these planes.

The ballonet for air had a capacity of 22,958 cubic feet, or about one-fifth of the total volume. This is calculated to permit reaching a height of about 1 mile and to be able to return to the earth, keeping the gas bag always rigid. To descend from a height of 1 mile gas would be released by the valve, then air pumped into the ballonet to keep the gas bag rigid, these two operations being carried on alter-

French Dirigible "Patrie."



FRENCH DIRIGIBLE "PATRIE;" DETAILS OF CAR.

nately. On reaching the ground from the height of 1 mile the air would be at the middle of the lower part of the gas bag and would not entirely fill the ballonet. To prevent the air from rolling from one end to the other when the airship pitches, thus producing instability, the ballonet was divided into three compartments by impermeable cloth partitions. Numerous small holes were pierced in these partitions through which the air finally reached the two end compartments.

In September, 1907, the Patrie was enlarged by 17,660 cubic feet by the addition of a cylindrical section at the maximum diameter, increasing the length but not the maximum diameter.

The gas bag is cut in panels; the material is a rubber cloth made by the Continental Tire Company at Hanover, Germany. It consists of four layers, arranged as follows:

	Weight, ounces, per square yard.
Outer layer of cotton cloth covered with lead chromate	2.5
Layer of vulcanized rubber	2.5
Layer of cotton cloth	2.5
Inner layer of vulcanized rubber	2.21
Total weight	9.71

A strip of this cloth 1 foot wide tears at a tension of about 934 pounds. A pressure of about one inch of water can be maintained in the gas bag without danger. The lead chromate on the outside is to prevent the entrance of the actinic rays of the sun, which would cause the rubber to deteriorate. The heavy layer of rubber is to prevent the leaking of the gas. The inner layer of rubber is merely to prevent deterioration of the cloth by impurities in the gas. This material has the warp of the two layers of cotton cloth running in the same direction and is called straight thread. The material in the ballonet weighs only about 7¾ ounces per square yard, and has a strength of about 336 pounds per running foot. When the Patrie was enlarged, in September, 1907, the specifications for the material allowed a maximum weight of 10 ounces per square yard, a minimum strength of 907 pounds per running foot, and a loss of 5.1 cubic inches of hydrogen per square yard in twenty-four hours at a pressure of 1.18 inches of water. Bands of cloth are pasted over the seams inside and out with a solution of rubber to prevent leaking through the stitches.

Suspension.—One of the characteristics of the Patrie is the "short" suspension. The weight of the car is distributed over only about 70 feet of the length of the gas bag. To do this, an elliptical shaped frame of nickel steel tubes is attached to the bottom of the gas bag; steel cables run from this down to the car. A small hemp net is attached to the gas bag by means of short wooden cross pieces or toggles, which are let into holes in a strong canvas band which is

sewed directly on the gas bag. The metal frame, or platform, is attached to this net by means of toggles, so that it can be quickly removed in dismounting the airship for transportation. The frame can also be taken apart. Twenty-eight steel cables about 0.2 inch in diameter run from the frame down to the car, and are arranged in triangles. Due to the impossibility of deforming a triangle, rigidity is maintained between the car and gas bag.

The objection to the "short" suspension of the Patrie is the deformation of the gas bag. A distinct curve can be seen in the middle.

Car.—The car is made of nickel steel tubes (12 per cent nickel). This metal gives the greatest strength for minimum weight. The car is boat-shaped, about 16 feet long, about 5 feet wide, and 2½ feet high. About 11 feet separate the car from the gas bag. To prevent any chance of the fire from the engine communicating with the hydrogen, the steel framework under the gas bag is covered with a noncombustible material.

The pilot stands at the front of the car, the engine is in the middle, the engineer at the rear. Provision is made for mounting a telephotographic apparatus, and for a 100-candlepower acetylene searchlight. A strong pyramidal structure of steel is built under the car, pointing downward. In landing, the point comes to the ground first and this protects the car, and especially the propellers, from being damaged. The car is covered to reduce air resistance. It is so low, however, that part of the equipment and most of the bodies of those inside are exposed, so that the total resistance of the car is large.

Motor.—The first Lebaudy had a 40 horsepower Daimler-Mercedes benzine motor. The Patrie was driven by a 60 to 70 horsepower, 4-cylinder Panhard and Levassor benzine motor, making 1,000 revolutions per minute.

Propellers.—There are two steel propellers 8½ feet in diameter (two blades each) placed at each side of the engine, thus giving the shortest and most economical transmission. To avoid any tendency to twist the car, the propellers turn in opposite directions. They are "high speed," making 1,000 to 1,200 revolutions per minute.

The gasoline tank is placed under the car inside the pyramidal frame. The gasoline is forced up to the motor by air compression. The exhaust is under the rear of the car, pointing down, and is covered with a metal gauze to prevent flames coming out. The fan which drives the air into the ballonet is run by the motor, but a dynamo is also provided so that the fan can always be kept running even if the motor stops. This is very essential, as the pressure must be maintained inside the gas bag so that the latter will remain rigid and keep its form. There are five valves in all, part automatic and part both automatic and also controlled from the car with cords. The valves in the ballonet open automatically at less pressure than the gas valves,

so that when the gas expands all the air is driven out of the ballonet before there is any loss of gas. The ballonet valves open at a pressure of about 0.78 inch of water, the gas valves at about 2 inches.

Stability.—Vertical stability is maintained by means of fixed horizontal planes. One having a surface of 150 square feet is attached at the rear of the gas bag, and due to its distance from the center of gravity is very efficient. The elliptical frame attached under the gas bag has an area of 1,055 square feet, but due to its proximity to the center of gravity has little effect on the stability. Just behind the elliptical frame is an arrangement similar to the feathering on an arrow. It consists of a horizontal plane of 150 square feet and a vertical plane of 113 square feet. To maintain horizontal stability, that is, to enable the airship to move forward in a straight line without veering to the sides, fixed vertical planes are used. One runs from the center to the rear of the elliptical frame and has an area of 108 square feet.

In addition to the vertical surface of 113 square feet at the rear of the elliptical frame, there is a fixed plane of 150 square feet at the rear of the gas bag. To fasten the two perpendicular planes at the rear of the gas bag, cloth flaps are sewed directly on the gas bag. Nickel-steel tubes are placed in the flaps which are then laced over the tubes. With these tubes as a base a light tube and wire framework is attached and waterproof cloth laced on this framework. Additional braces run from one surface to the other and from each surface to the gas bag. The rudder is at the rear under the gas bag. It has about 150 square feet and is balanced.

A movable horizontal plane near the center of gravity, above the car, is used to produce rising or descending motion, or to prevent an involuntary rising or falling of the airship due to expansion or contraction of the gas or to other causes. After the adoption of this movable horizontal plane the loss of gas and ballast was reduced to a minimum. Ballast is carried in 10 and 20 pound sand bags. A pipe runs through the bottom of the car from which the ballast is thrown.

There are two long guide ropes, one attached at the front of the elliptical frame and the other on the car. On landing, the one in front is seized first, so as to hold the airship with the head to the wind. The motor may then be stopped and the descent made by pulling down on both guide ropes. A heavy rope, 22 feet long, weighing 110 pounds, is attached on the end of a 164-foot guide rope. This can be dropped out on landing to prevent coming to the ground too rapidly. The equipment of the car includes a "siren," speaking trumpet, carrier pigeons, iron pins and a rope for anchoring the airship, reserve supply of fuel and water, and fire extinguisher.

After being enlarged in September, 1907, the Patrie made a number of long trips at an altitude of 2,500 to 3,000 feet. In November,

1907, she went from Paris to Verdun, near the German frontier, a distance of about 175 miles, in about seven hours, carrying four persons. This trip was made in a light wind blowing from the northeast. Her course was east, so that the wind was unfavorable. On Friday, November 29, 1907, during a flight near Verdun, the motor stopped due to difficulty with the carburetor. The airship drifted with the wind to a village about 10 miles away, where she was safely landed. The carburetor was repaired on the 30th. Soon after, a strong wind came up and tore loose some of the iron pickets with which it was anchored. This allowed the air ship to swing broadside to the wind; it then tilted over on the side far enough to let some of the ballast bags fall out. The 150 or 200 soldiers who were holding the ropes were pulled along the ground until directed by the officer in charge to let go. After being released, it rose and was carried by the wind across the north of France, the English Channel, and into the north of Ireland. It struck the earth there, breaking off one of the propellers and then drifted out to sea.

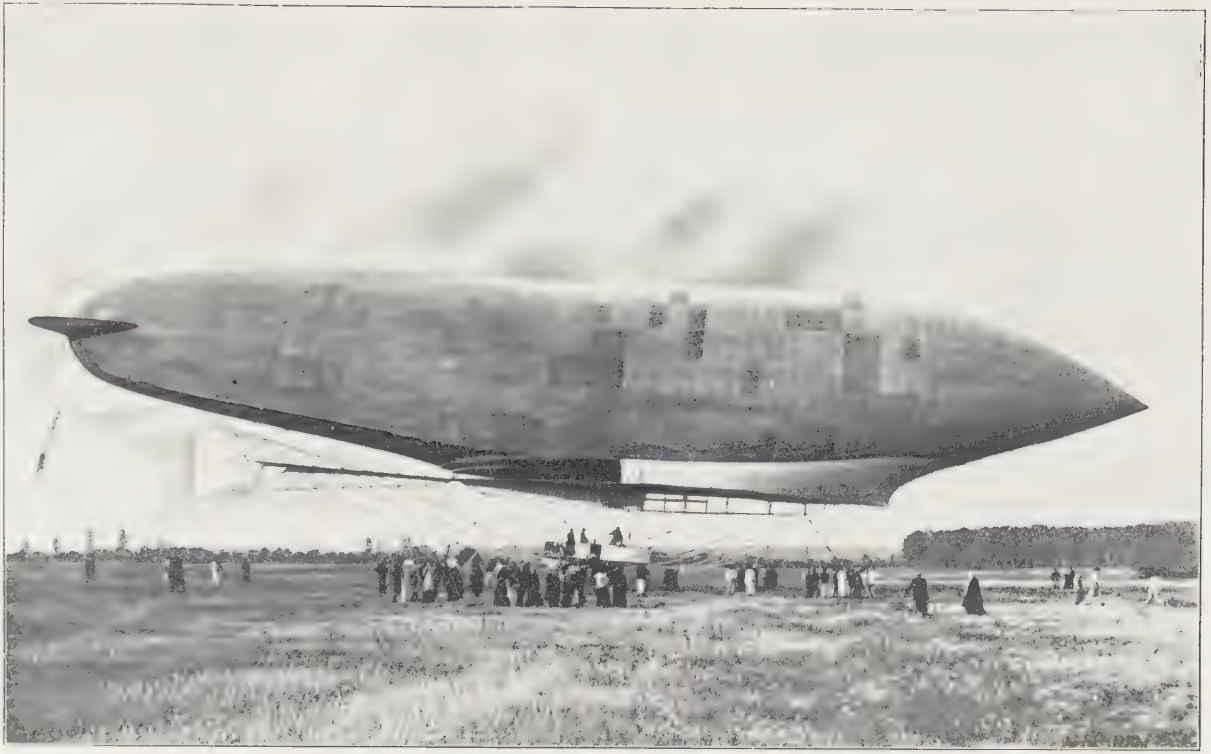
The Republique.

This is the latest of the French military dirigible balloons, and differs but slightly from its predecessor, the Patrie. The volume has been increased by about 2,000 cubic feet. The length has been reduced to 200 feet and the maximum diameter increased to 35½ feet. The shape of the gas bag accounts for the 2,000 additional cubic feet of volume. The motor and propellers are as in the Patrie. The total lifting capacity is 9,000 pounds, of which 2,700 pounds are available for passengers, fuel, ballast, instruments, etc. Its best performance was a 125-mile flight made in six and one-half hours against an unfavorable wind.

The material for the gas bag of the new airship was furnished by the Continental Tire Company. It is made up as follows:

	Weight, ounces per square yard.
Outer yellow cotton layer	3.25
Layer of vulcanized rubber	3.25
Layer of cotton cloth	3.25
Inner layer of rubber	.73
Total weight	10.48

It is interesting to note the changes which this type has undergone since the first one was built. The Jaune, constructed in 1902–3, was pointed at the rear and had no stability plane there; later it was rounded off at the rear and a fixed horizontal plane attached. Finally a fixed vertical plane was added. The gas bag has been increased in capacity from 80,670 cubic feet to about 131,000 cubic feet. The manufacturers have been able to increase the strength of



FRENCH DIRIGIBLE "RÉPUBLIQUE."

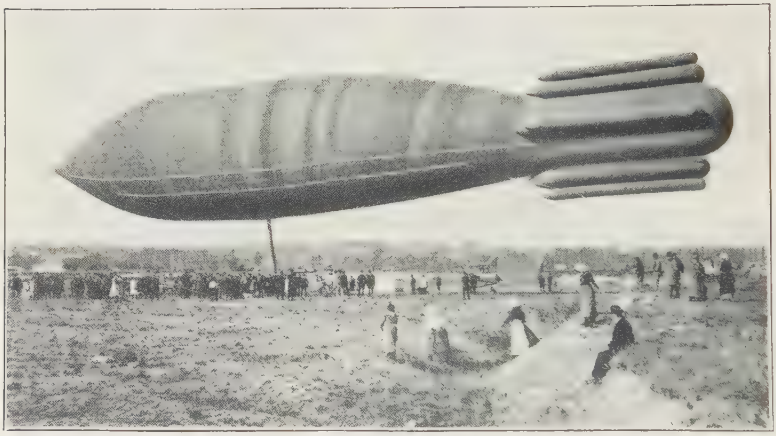


FIG. 1.—FRENCH DIRIGIBLE "LA VILLE DE PARIS."

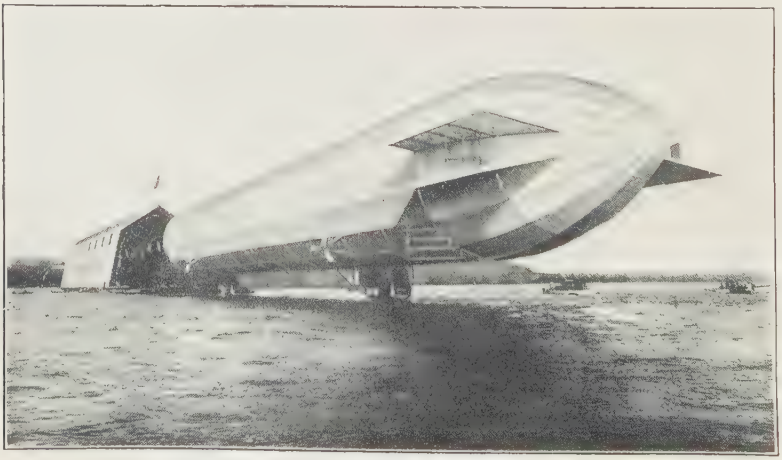


FIG. 2.—GERMAN DIRIGIBLE "ZEPPELIN," WITH FLOATING HANGAR.

the material of which the gas bag is made without materially increasing the weight. The rudder has been altered somewhat in form. It was first pivoted on its front edge, but later on a vertical axis, somewhat to the rear of this edge. With the increase in size has come an increase in carrying capacity, and consequently a greater speed and more widely extended field of action.

Ville de Paris.

This airship was constructed for Mr. Deutsch de la Meurthe, of Paris, who has done a great deal to encourage aerial navigation. The first Ville de Paris was built in 1902, on plans drawn by Tatin, a French aeronautical engineer. It was not a success. Its successor was built in 1906, on plans of Surcouf, an aeronautical engineer and balloon builder. The gas bag was built at his works in Billancourt, the mechanical part at the Voisin shop, also in Billancourt. The plans are based on those of Colonel Renard's airship, the France, built in 1884, and the Ville de Paris resembles the older airship in many particulars. In September, 1907, Mr. Deutsch offered the use of his airship to the French Government. The offer was accepted, but delivery was not to be made except in case of war or emergency. When the Patrie was lost in November, 1907, the military authorities immediately took over the Deutsch airship.

Gas bag.—The gas bag is 200 feet long for a maximum diameter of 34½ feet, giving a length of about 6 diameters, as in the France and the Patrie; volume, 112,847 cubic feet; maximum diameter at about three-eighths of the distance from the front, approximately, as in the Patrie. The middle section is cylindrical, with conical sections in front and rear. At the extreme rear is a cylindrical section with eight smaller cylinders attached to it. The ballonet has a volume of 21,192 cubic feet, or about one-fifth of the whole volume, the same proportion found in the Patrie. The ballonet is divided into three compartments from front to rear. The division walls are of permeable cloth, and are not fastened to the bottom, so that when the middle compartment fills with air and the ballonet rises the division walls are lifted up from the bottom of the gas bag and there is free communication between the three compartments. The gas bag is made up of a series of strips perpendicular to a meridian line. These strips run around the bag, their ends meeting on the under meridian. This is known as the "brachistode" method of cutting out the material, and has the advantage of bringing the seams parallel to the line of greatest tension. They are, therefore, more likely to remain tight and not allow the escape of gas. The disadvantage lies in the fact that there is a loss of 33⅓ per cent of material in cutting. The material was furnished by the Continental Tire Company, and has approximately the same tensile strength and

weight as that used in the Patrie. It differs from the other in one important feature—it is diagonal-thread; that is, the warp of the outer layer of cotton cloth makes an angle of 45° with the warp of the inner layer of cotton cloth. The result is to localize a rip or tear in the material. A tear in the straight-thread material will continue along the warp, or the weave, until it reaches a seam.

Valves.—There are five in all, made of steel, about 14 inches in diameter—one on the top connected to the car by a cord operated by hand only; two near the rear underneath. These are automatic but can be operated by hand from the car. Two ballonet valves directly under the middle are automatic and are also operated from the car by hand. The ballonet valves open automatically at a pressure of two-thirds of an inch of water; the gas valves open at a higher pressure.

Suspension.—This airship has the "long" suspension: that is, the weight is distributed along practically the entire length of the gas bag. A doubled band of heavy canvas is sewn with six rows of stitches along the side of the gas bag. Hemp ropes running into steel cables transmit most of the weight of the car to these two canvas bands and thus to the gas bag. On both sides and below these first bands are two more. Lines run from these to points half way between the gas bag and the car, then radiate from these points to different points of attachment on the car. This gives the triangular or nondeformable system of suspension, which is necessary in order to have the car and gas bag rigidly attached to each other. With this "long" suspension, the Ville de Paris does not have the deformation so noticeable in the gas bag of the Patrie.

Car.—This is in the form of a trestle. It is built of wood, with aluminum joints and 0.12-inch wire tension members. It is 115 feet long, nearly 7 feet high at the middle, and a little over 5½ feet wide at the middle. It weighs 660 pounds and is considered unnecessarily large and heavy. The engine and engineer are well to the front; the aeronaut with steering wheels is about at the center of gravity.

Motor.—The motor is a 70 to 75 horsepower "Argus," and is exceptionally heavy.

Propeller.—The propeller is placed at the front end of the car. It thus has the advantage of working in undisturbed air; the disadvantage is the long transmission and difficulty in attaching the propeller rigidly. It has two blades and is 19.68 feet long with a pitch of 26.24 feet. The blades are of cedar with a steel arm. The propeller makes a maximum of 250 turns per minute when the engine is making 900 revolutions. Its great diameter and width compensate for its small speed.

Stability.—This is maintained entirely by the cylinders at the rear. Counting the larger one to which the smaller ones are attached, there are five, arranged side by side corresponding to the horizontal planes of the Patrie, and five vertical ones corresponding to the Patrie's vertical planes. The volume of the small cylinders is so calculated that the gas in them is just sufficient to lift their weight, so they neither increase or decrease the ascensional force of the whole. The horizontal projection of these cylinders is 1,076 square feet. The center of this projection is 72 feet from the center of gravity of the gas. The great objection to this method of obtaining stability is the air resistance due to these cylinders, and consequent loss of speed. The stability of the Ville de Paris in a vertical plane is said to be superior to that of the Patrie, due to the fact that the stability planes of the latter do not always remain rigid. The independent velocity of the Ville de Paris probably never exceeded 25 miles an hour.

Rudder.—The rudder has a double surface of 150 square feet placed at the rear end of the car, 72 feet from the center of gravity. It is not balanced, but is inclined slightly to the rear so that its weight would make it point directly to the rear if the steering gear should break. Two pairs of movable horizontal planes, one at the rear of the car having 43 square feet, and one at the center of gravity (as on the Patrie) having 86 square feet, serve to drive the airship up or down without losing gas or ballast.

Guide ropes.—A 400-foot guide rope is attached at the front end of the car. A 230-foot guide rope is attached to the car at the center of gravity.

About thirty men are required to maneuver the Ville de Paris on the ground. The pilot has three steering wheels, one for the rudder and two for the movable horizontal planes. The instruments used are an aneroid barometer, a registering barometer giving heights up to 1,600 feet, and an ordinary dynamometer which can be connected either with the gas bag or ballonet by turning a valve. A double column of water is also connected to the tube to act as a check on the dynamometer. Due to the vibration of the car caused by the motor, these instruments are suspended by rubber attachments. Even with this arrangement it is necessary to steady the aneroid barometer with the hand in order to read it. The vibration prevents the use of the statoscope.

England.

Military Dirigible No. 1.

The gas bag of this airship was built about five years ago by Colonel Templar, formerly in command of the aeronautical establishment at Aldershot. His successor, Colonel Capper, built the me-

chanical part during the spring and summer of 1907, with the assistance of Mr. S. F. Cody, a mechanical engineer. It was operated by Colonel Capper as pilot, with Mr. Cody in charge of the engine. Several ascents were made at Aldershot. In October, 1907, they made a trip from Aldershot to London, a distance of about 40 miles, landing at the Crystal Palace. For several days the rain and wind prevented attempting the return journey. On October 10 a strong wind threatened to carry away the airship, so the gas bag was cut open by the sergeant in charge.

Gas bag.—This is made of eight layers of gold beater's skin. It is cylindrical in shape with spherical ends. Volume, 84,768 cubic feet; length, 111½ feet; maximum diameter, 31½ feet. The elongation therefore is only about 3⅔. There is no ballonet, but due to the toughness of the gold beater's skin a much higher pressure can safely be maintained than in gas bags of rubber cloth. Without a ballonet, however, it would not be safe to rise to the heights reached by the Patrie.

Valves.—The valves are made of aluminum and are about 12 inches in diameter.

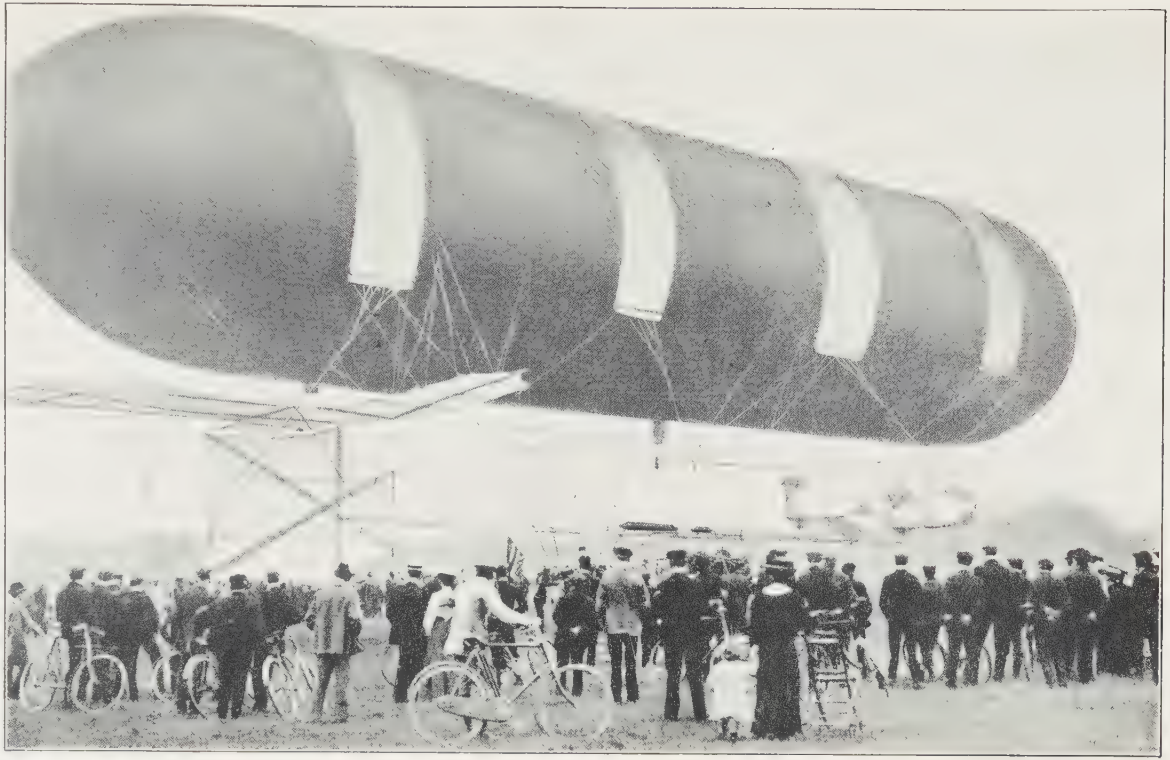
Suspension.—In this airship they have succeeded in obtaining a "long" suspension with a short boat-shaped car, a combination very much to be desired, as it distributes the weight over the entire length of the gas bag and gives the best form of car for purposes of observation and for maneuvering on the ground. To obtain this combination they have had to construct a very heavy steel framework, which cuts down materially the carrying capacity, and, moreover, this framework adds greatly to the air resistance. This is the only airship in Europe having a network to support the car. In addition, four silk bands are passed over the gas bag and wires run from their extremities down to the steel frame. This steel frame is in two tiers—the upper is rectangular in cross section and supports the rudder and planes, the lower part is triangular in cross section and supports the car. The joints are aluminum.

Car.—This is of steel and is about 30 feet long. To reduce air resistance the car is covered with cloth.

Motor.—A 40 to 50 horsepower 8-cylinder Antoinette motor is used. It is set up on top of the car. The benzine tanks are supported above in the framework. Gravity feed is used.

Propellers.—There are two propellers, one on each side, with two blades each, as in the Patrie. They are made of aluminum, 10 feet in diameter, and make 700 revolutions per minute. The transmission is by belt.

Stability.—This is maintained by means of planes. At the extreme rear is a large fixed horizontal plane. In front of this is a pair of hinged horizontal planes. Under this is the hexagonal-shaped rud-



ENGLISH DIRIGIBLE NO. 1.

GERMAN DIRIGIBLE "ZEPPELIN;" DETAILS OF CAR.

der. It is balanced. Two pairs of movable horizontal planes, 8 feet by 4 feet, each placed at the front, serve to guide the airship up and down, as in the Patrie and Ville de Paris. These planes have additional inclined surfaces, which are intended to increase the stability in a vertical plane. All these planes, both fixed and movable, are constructed like kites, of silk stretched on bamboo frames. The guide rope is 150 feet long. Speed attained, about 16 miles per hour. This airship with a few improvements added has been in operation the past few months. The steel framework connecting the gas bag to the car is now entirely covered with canvas, which must reduce the resistance of the air very materially. The canvas covering, inclosing the entire bag, serves as a reinforcement to the latter and at the same time gives attachment to the suspension underneath. It is reported that a speed of 20 miles an hour has been attained with the reconstructed airship.

A pyramidal construction similar to that on the Patrie has been built under the center of the car to protect the car and propellers on landing. A single movable horizontal plane placed at the front end of the car and operated by the pilot, controls the vertical motion.

Germany.

Three different types of airships are being developed in Germany. The Gross is the design of Major Von Gross, who commands the balloon battalion at Tegel, near Berlin. The Parseval is being developed by Major Von Parseval, a retired German officer, and the Zeppelin is the design of Count Zeppelin, also a retired officer of the German army.

The Gross.

The first airship of this type made its first ascension on July 23, 1907. The mechanical part was built at Siemen's Electrical Works in Berlin; the gas bag by the Riedinger firm in Augsburg.

Gas bag.—The gas bag is made of rubber cloth furnished by the Continental Tire Company, similar to that used in the Ville de Paris. It is diagonal thread, but there is no inner layer of rubber, as they do not fear damage from impurities in the hydrogen gas. Length, 131¼ feet; maximum diameter, about 39⅜ feet; volume, 63,576 cubic feet. The elongation is about 3⅛. The form is cylindrical with spherical cones at the ends, the whole being symmetrical.

Suspension.—The suspension is practically the same as that of the Patrie. A steel and aluminum frame is attached to the lower part of the gas bag, and the car is suspended on this by steel cables. The objection to this system is even more apparent in the Gross than in the Patrie. A marked dip along the upper meridian of the gas bag shows plainly the deformation.

Car.—The car is boat shaped, like that of the Patrie. It is suspended 13 feet below the gas bag.

Motor.—The motor is a 20 to 24 horsepower, four-cylinder Daimler-Mercedes.

Propellers.—There are two propellers 8.2 feet in diameter, each having two blades. They are placed one on each side, but well up under the gas bag near the center of resistance. The transmission is by belt. The propellers make 800 revolutions per minute.

Stability.—The same system, with planes, is used in the Von Gross as in the Patrie, but it is not nearly so well developed. At the rear of the rigid frame attached to the gas bag are two fixed horizontal planes, one on each side. A fixed vertical plane runs down from between these horizontal planes, and is terminated at the rear by the rudder. A fixed horizontal plane is attached on the rear of the gas bag, as in the Patrie. The method of attachment is the same, but the plane is put on before the inflation in the Gross airship, afterwards in the Patrie. The stability of the Gross airship in a vertical plane is reported to be very good, but it is said to veer considerably in attempting to steer a straight course.

The many points of resemblance between this dirigible and the Lebaudy type are worthy of notice. The suspension or means of maintaining stability and the disposition for driving are in general the same. As first built the Gross had a volume of 14,128 cubic feet less than at present, and there was no horizontal plane at the rear of the gas bag. Its maximum speed is probably 15 miles per hour. As a result of his experiments of 1907, Major Von Gross has this year produced a perfected airship built on the same lines as his first, but with greatly increased volume and dimensions. The latest one has a volume of 176,000 cubic feet, is driven by two 75-horsepower Daimler motors, and has a speed of 27 miles per hour.

On September 11, 1908, the Gross airship left Berlin at 10.25 p. m., carrying four passengers, and returned the next day at 11.30 a. m., having covered 176 miles in the period of a little over thirteen hours. This is the longest trip to date, both in point of time and distance, ever made by any airship returning to the starting point.

The Parseval.

The Parseval airship is owned and controlled by the Society for the Study of Motor Balloons. This organization, composed of capitalists, was formed practically at the command of the Emperor, who is very much interested in aerial navigation. The society has a capital of 1,000,000 marks, owns the Parseval patents, and is ready to construct airships of the Von Parseval type. The present airship was constructed by the Riedinger firm at Augsburg, and is operated from

the balloon house of this society at Tegel, adjoining the military balloon house.

The gas bag is similar in construction to that of the Drachen balloon, used by the army for captive work; volume, 113,000 cubic feet; length, 190 feet; maximum diameter, 30½ feet. It is cylindrical in shape, rounded at the front end, and pointed at the rear. The material was furnished by the Continental Tire Company. It is diagonal-thread, weighing about 11.2 ounces per square yard, and having a strength of about 940 pounds per running foot. Its inner surface is covered with a layer of rubber.

Ballonets.—There are two ballonets, one at each end, each having a capacity of 10,596 cubic feet. The material in the ballonet weighs about 8¼ ounces per square yard, the cotton layers being lighter than in the material for the gas bag. Air is pumped into the rear ballonet before leaving the ground, so that the airship operates with the front end inclined upward. The air striking underneath exerts an upward pressure, as on an aeroplane, and thus adds to its lifting capacity. Air is pumped into the ballonets from a fan operated by the motor. A complex valve just under the middle of the gas bag enables the engineer to drive air into either or both ballonets. The valves also act automatically and release air from the ballonets at a pressure of about 0.9 of an inch of water.

In the middle of the top of the gas bag is a valve for releasing the gas. It can be operated from the car, and opens automatically at a pressure of about 2 inches of water. Near the two ends and on opposite sides are two rip strips controlled from the car by cords.

Suspension.—The suspension is one of the characteristics of the airship and is protected by patents. The car has four trolleys, two on each side, which run on two steel cables. The car can run backward and forward on these cables, thus changing its position with relation to the gas bag. This is called "loose" suspension. Its object is to allow the car to take up, automatically, variations in thrust due to the motor and variations in resistance due to the air. Ramifications of hemp rope from these steel cables are sewn onto a canvas strip, which in turn is sewn onto the gas bag. This part of the suspension is the same as in the Drachen balloon. The weight is distributed over the entire length of the gas bag.

Car.—The car is 16.4 feet long and is built of steel tubes and wire. It is large enough to hold the motor and three men, though four or five may be taken.

Motor.—The motor is a 110-horsepower Daimler-Mercedes. Sufficient gasoline is carried for a run of twelve hours.

Propeller.—The propeller, like the suspension, is peculiar to this airship and is protected by patents. It has four cloth blades, which

hang limp when not turning. When the motor is running, these blades, which are carefully weighted with lead at certain points, assume the proper position due to the various forces acting. The diameter is 13¾ feet. The propeller is placed above the rear of the car near the center of resistance. Shaft transmission is used. The propeller makes 500 revolutions per minute to 1,000 of the motor. There is a space of 6½ feet from the propeller blades to the gas bag, the bottom of the car being about 30 feet from the gas bag. This propeller has the advantage of being very light. Its position, so far from the engine, necessarily incurs a great loss of power in transmission.

The steering wheel at the front of the car has a spring device for locking it in any position.

The 1908 model of this airship was constructed for the purpose of selling it to the Government. Among other requirements is a twelve-hour flight without landing and a sufficient speed to maneuver against a 22-mile wind. A third and larger air ship of this type is now under construction.

The Zeppelin.

The Zeppelin airship, of which there have been four, differs from all others in that the envelope is rigid. Sixteen separate gas bags are contained in an aluminum alloy framework having 16 sides, covered with a cotton and rubber fabric. The pressure of the air is taken up by this framework instead of by the gas bags. The gas bags are not entirely filled, thus leaving room for expansion.

The rigid frame is 446 feet long, 42½ feet in diameter, and has ogival-shaped ends. It is braced about every 45 feet by a number of rods crossing near the center, giving a cross section resembling a bicycle wheel. Vertical braces are placed at intervals the entire length of the frame. The 16 gas bags are completely separated from each other by partitions of sheet aluminum. Under the framework is a triangular truss running nearly the entire length, the sides of the triangle being about 8 feet. The total volume of the gas bags is 460,000 cubic feet, which gives a gross lift of about 32,000 pounds.

Suspension.—The two cars are rigidly attached directly to the frame of the envelope and a very short distance below it.

Cars.—The two cars are built like boats. They are about 20 feet long, 6 feet wide, 3¾ feet high; are placed about 100 feet from each end and are made of the same aluminum alloy. To land the airship, it is lowered until the cars float on the water, when it can be towed like a ship. A third car is built into the keel directly under the center of the framework, and is for passengers only.

Motors.—The power is furnished by two 110-horsepower Daimler-Mercedes motors, one placed on each car. Each weighs about 550 pounds; sufficient fuel for a sixty-hours' run can be carried.

Propellers.—A pair of three-bladed metal propellers about 15 feet in diameter is placed opposite each car, firmly attached to the frame of the envelope at the height of the center of resistance, where they are most efficient.

Stability.—In addition to the long V-shaped keel under the rigid frame, on each side at the rear of the frame are two nearly horizontal planes, while above and below the rear end are vertical fins.

Steering.—A large vertical rudder is attached at the extreme end of the rigid frame, and an additional one is placed between each set of horizontal planes on the sides. For vertical steering there are four sets of movable horizontal planes placed near the ends of the rigid frame, about the height of the propellers. Each set consists of four horizontal planes placed one above the other and connected with rods, so that they work on the principle of a shutter. These horizontal rudders serve another very important purpose, due to the reaction of the air. When these planes are set at an angle of 15° and the airship is making a speed of 35 miles per hour, an upward pressure of over 1,700 pounds is exerted, and consequently all the gas in one compartment could escape and yet by the manipulation of these planes the airship could return safely to its starting point.

Its best performances were two trips made during the past summer [1908]. The first, July 4, lasted exactly twelve hours, during which time it covered a distance of 235 miles, crossing the mountains to Lucerne and Zurich, and returning to the balloon house at Friedrichshafen, on Lake Constance. The average speed on this trip was 32 miles per hour. On August 4 this airship attempted a twenty-four-hour flight, which was one of the requirements made for its acceptance by the Government. It left Friedrichshafen in the morning with the intention of following the Rhine as far as Mainz and then returning to its starting point straight across the country. A stop of four hours and thirty minutes was made in the afternoon of the first day on the Rhine, to repair the engine. On the return, a second stop was found necessary near Stuttgart, due to difficulties with the motors and the loss of gas. While anchored to the ground a storm came up and broke loose the anchorages, and as the balloon rose in the air it exploded and took fire, due to causes which have never been actually determined and published, and fell to the ground, resulting in its complete destruction. On this journey, which lasted in all thirty-one hours and fifteen minutes, the airship was in the air twenty hours and forty-five minutes and covered a total distance of 378 miles.

The patriotism of the German nation was aroused. Subscriptions were immediately opened and in a short space of time $1,000,000 had been raised. A Zeppelin society was formed to direct the expenditure of this fund. Eighty-five thousand dollars has been expended

for land near Friedrichshafen; shops are being constructed, and it has been announced that within one year the construction of 8 airships of the Zeppelin type will be completed. Recently the Crown Prince of Germany made a trip in the Zeppelin No. 3, which had been called back into service, and within a very few days the Emperor of Germany visited Friedrichshafen for the purpose of seeing the airship in flight. He decorated Count Zeppelin with the Order of the Black Eagle. German patriotism and enthusiasm has gone further, and the German Association for an Aerial Fleet has been organized in sections throughout the country. It announces its intention of building 50 garages (hangars) for housing airships.

United States.

Signal Corps, Dirigible No. 1.

Due to unavailability of funds, the United States Government has not been able to undertake the construction of an airship sufficiently large and powerful to compete with those of European nations. However, specifications were sent out January, 1908, for an airship not over 120 feet long and capable of making 20 miles per hour. Contract was awarded to Capt. Thomas S. Baldwin, who delivered an airship in August, 1908, to the Signal Corps, the description of which follows:

Gas bag.—The gas bag is spindle shaped, 96 feet long, maximum diameter 19 feet 6 inches, with a volume of 20,000 cubic feet. A ballonet for air is provided inside the gas bag, and has a volume of 2,800 cubic feet. The material for the gas bag is made of two layers of Japanese silk with a layer of vulcanized rubber between.

Car. The car is made of spruce, and is 66 feet long, 2½ feet wide, and 2½ feet high.

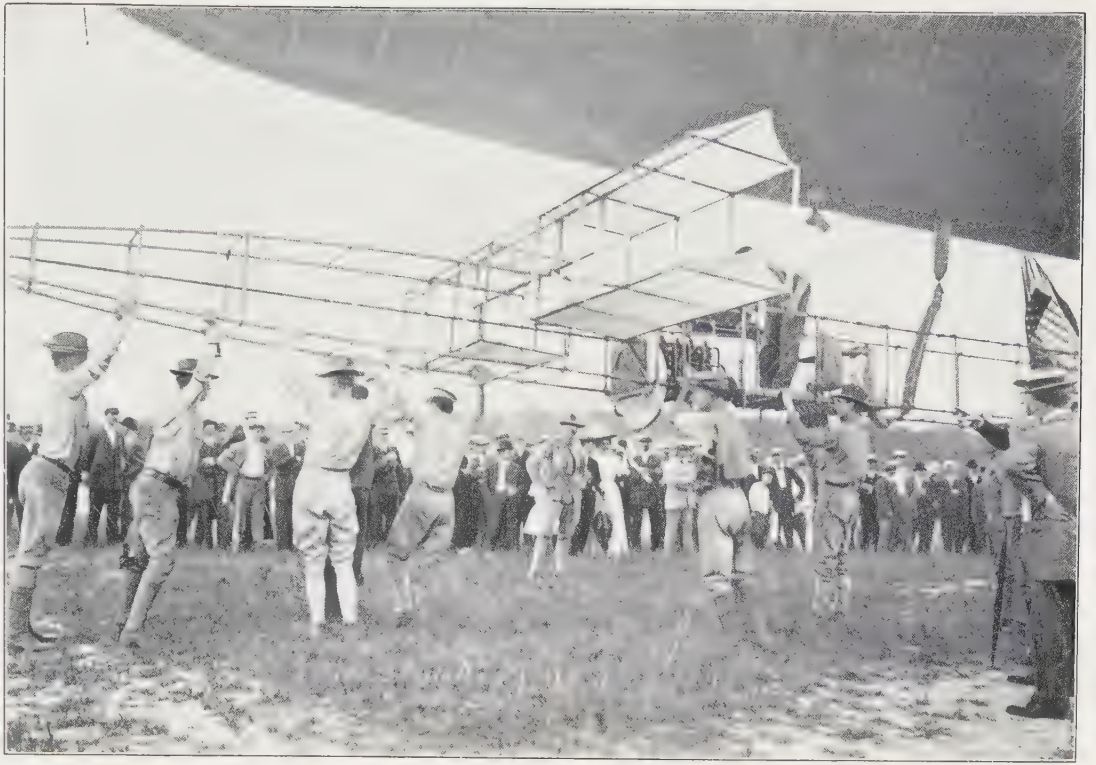
Motor. The motor is a 20 horsepower, water-cooled Curtiss make.

Propeller. The propeller is at the front end of the car, and is connected to the engine by a steel shaft. It is built up of spruce, has a diameter of 10 feet 8 inches, with a pitch of 11 feet, and turns at the rate of 150 revolutions per minute. A fixed vertical surface is provided at the rear end of the car to minimize veering, and a horizontal surface attached to the vertical rudder at the rear tends to minimize pitching. A double horizontal surface controlled by a lever and attached to the car in front of the engine serves to control the vertical motion and also to minimize pitching.

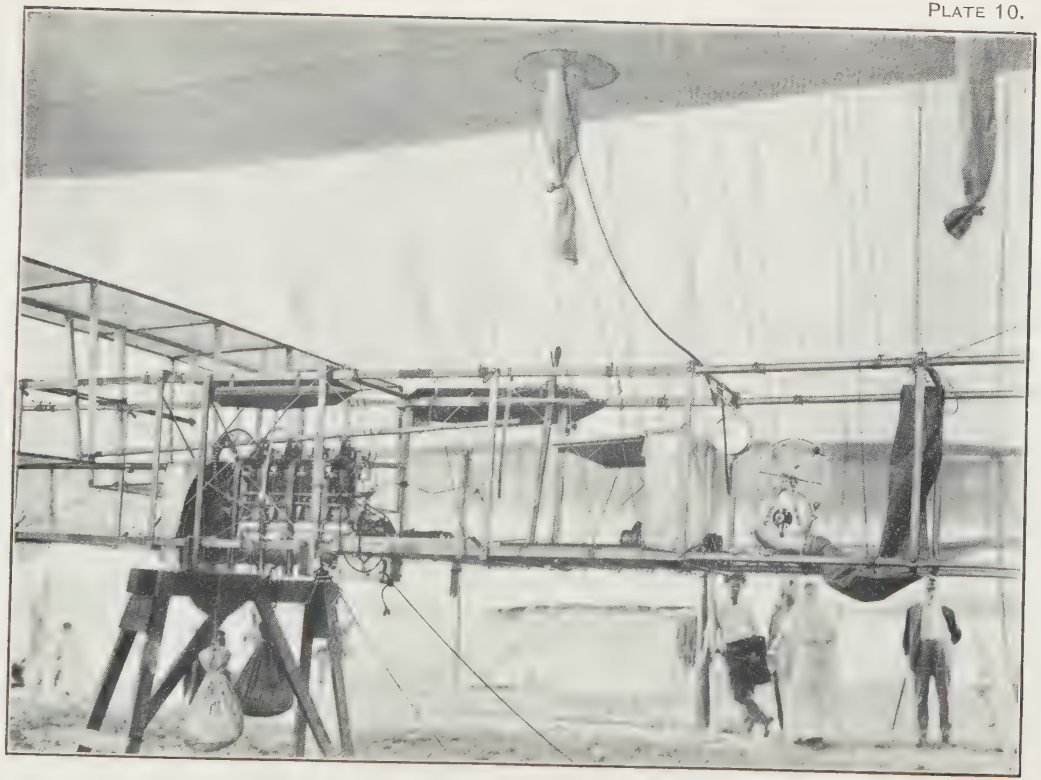
The position of the car very near to the gas bag is one of the features of the government dirigible. This reduces the length and consequently the resistance of the suspension, and places the propeller thrust near the center of resistance.

SIGNAL CORPS DIRIGIBLE NO. 1, IN FLIGHT, FORT MYER, VA., AUGUST, 1908.

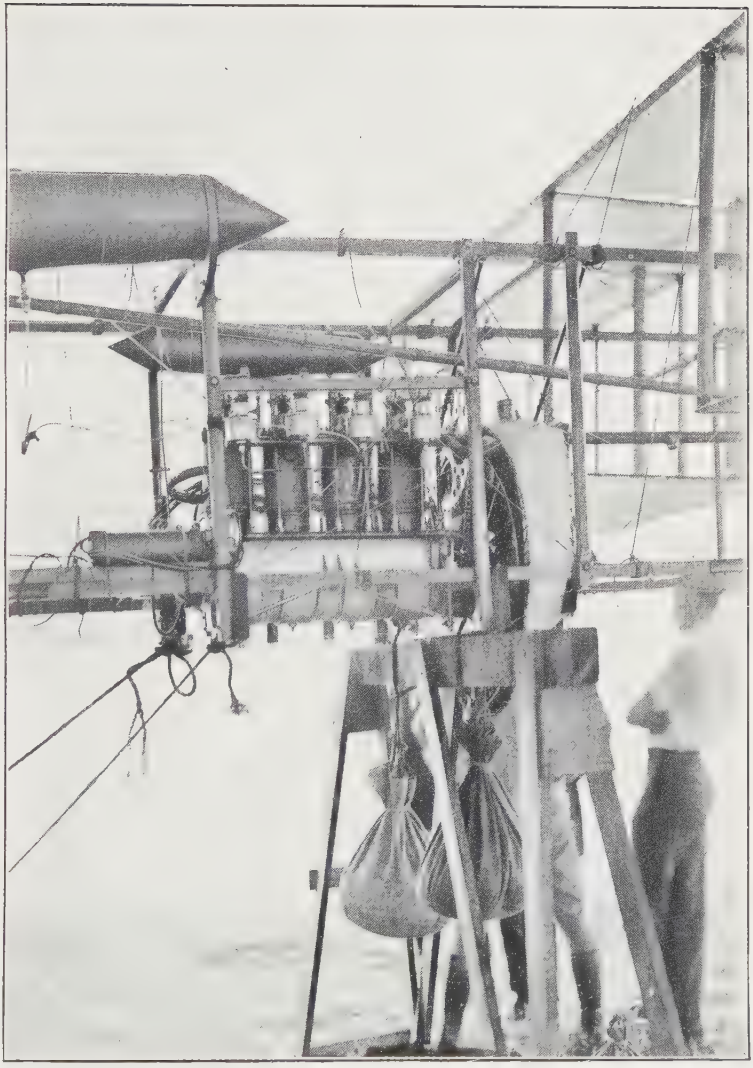
SIGNAL CORPS DIRIGIBLE NO. 1, IN FLIGHT, FORT MYER, VA., AUGUST, 1908.



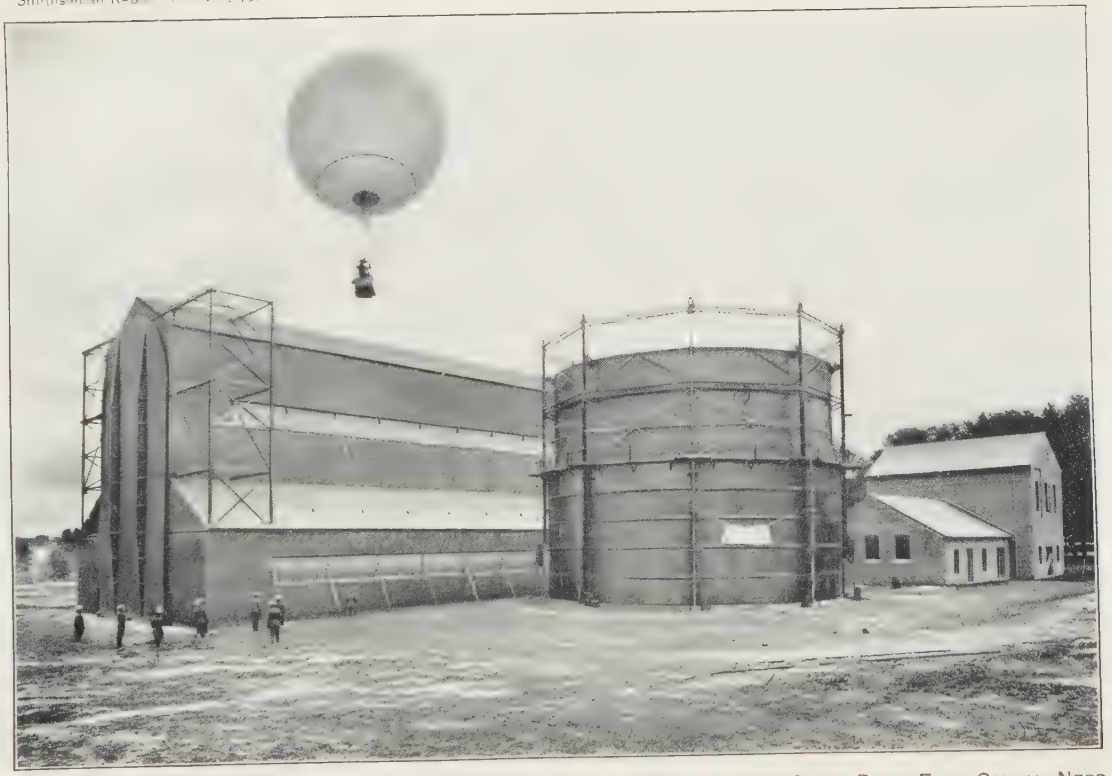
SIGNAL CORPS DIRIGIBLE NO. 1, SHOWING DETAILS OF FRONT MANEUVERING PLANES.



SIGNAL CORPS DIRIGIBLE NO. 1, SHOWING DETAILS OF CAR.



SIGNAL CORPS DIRIGIBLE NO. 1, SHOWING DETAILS OF ENGINE.



STEEL BALLOON HOUSE, GASOMETER, AND HYDROGEN GENERATING PLANT, SIGNAL CORPS POST, FORT OMAHA, NEBR.

The total lifting power of this airship is 1,350 pounds, of which 500 pounds are available for passengers, ballast, fuel, etc. At its official trials a speed of 19.61 miles per hour was attained over a measured course, and an endurance run lasting two hours, during which 70 per cent of the maximum speed was maintained.

Dirigible No. 1, as this airship has been named, has already served a very important purpose in initiating officers of the Signal Corps in the construction and operation of a dirigible balloon. With the experience now acquired the United States Government is in a position to proceed with the construction and operation of an airship worthy of comparison with any now in existence, but any efforts in this direction must await the action of Congress in providing the necessary funds. * * *

II. Aviation.

This division comprises all those forms of heavier-than-air flying machines which depend for their support upon the dynamic reaction of the atmosphere. There are several subdivisions of this class dependent upon the particular principle of operation. Among these may be mentioned the aeroplane, orthopter, helicopter, etc. The only one of these that has been sufficiently developed at present to carry a man in practical flight is the aeroplane. There have been a large number of types of aeroplanes tested with more or less success, and of these the following are selected for illustration.

Representative aeroplanes of various types.

The Wright Brothers' Aeroplane.

The general conditions under which the Wright machine was built for the Government were that it should develop a speed of at least 36 miles per hour and in its trial flights remain continuously in the air for at least one hour. It was designed to carry two persons having a combined weight of 350 pounds, and also sufficient fuel for a flight of 125 miles. The trials at Fort Myer, Virginia, in September of 1908, indicated that the machine was able to fulfill the requirements of the government specifications.

The aeroplane has two superposed main surfaces 6 feet apart, with a spread of 40 feet and a distance of $6\frac{1}{2}$ feet from front to rear. The area of this double supporting surface is about 500 square feet. The surfaces are so constructed that their extremities may be warped at the will of the operator.

A horizontal rudder of two superposed plane surfaces about 15 feet long and 3 feet wide is placed in front of the main surfaces. Behind the main planes is a vertical rudder formed of two surfaces

trussed together, about 5½ feet long and 1 foot wide. The auxiliary surfaces and the mechanism controlling the warping of the main surfaces are operated by three levers.

The motor, which was designed by the Wright brothers, has four cylinders and is water cooled. It develops about 25 horsepower at 1,400 revolutions per minute. There are two wooden propellers, 8½ feet in diameter, which are designed to run at about 400 revolutions per minute. The machine is supported on two runners, and weighs about 800 pounds. A monorail is used in starting.

The Wright machine has attained an estimated maximum speed of about 40 miles per hour. On September 12, a few days before the accident which wrecked the machine, a record flight of one hour fourteen minutes twenty seconds was made at Fort Myer, Virginia. Since that date Wilbur Wright, at Le Mans, France, has made better records, on one occasion remaining in the air for more than an hour and a half with a passenger.

A reference to the attached illustrations of this machine will show its details, its method of starting, and its appearance in flight.

The Herring Aeroplane.

The Signal Corps of the Army has contracted with A. M. Herring, of New York, to furnish an aeroplane under the conditions enumerated in the specification already referred to. Mr. Herring made technical delivery of his machine at the aeronautical testing ground at Fort Myer, Virginia, on October 13, 1908.

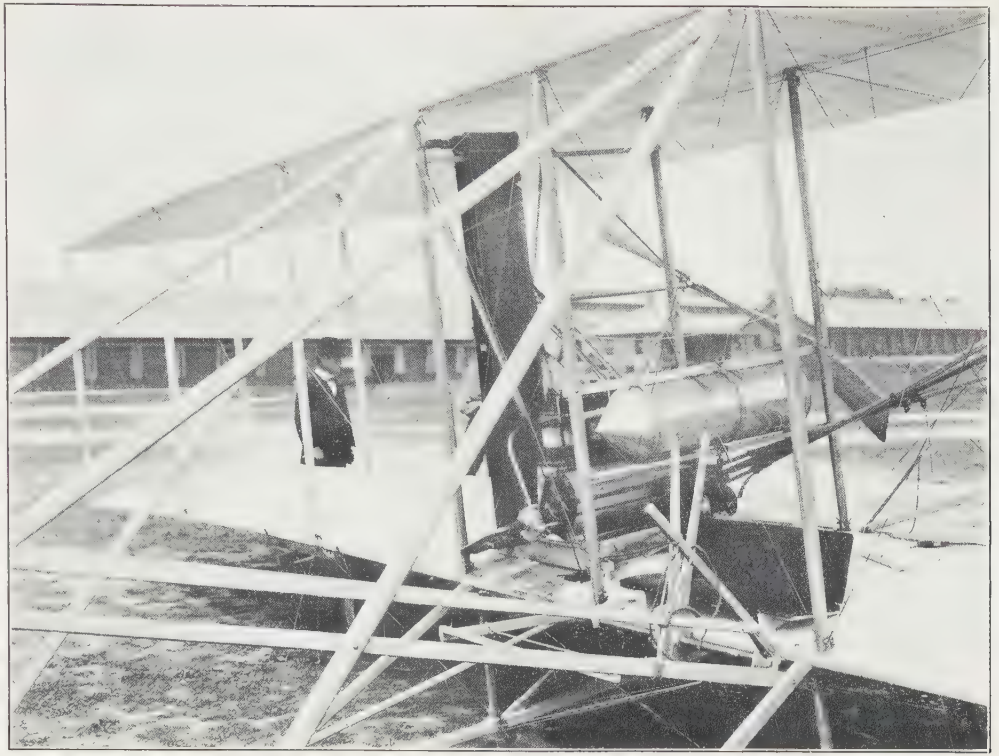
In compliance with the request of Mr. Herring the details of this machine will not be made public at present, but the official tests required under the contract will be conducted in public, as has been the case with other aeronautical devices. Opportunity will be afforded any one to observe the machine in operation.

This machine embodies new features for automatic control and contains an engine of remarkable lightness per horsepower.

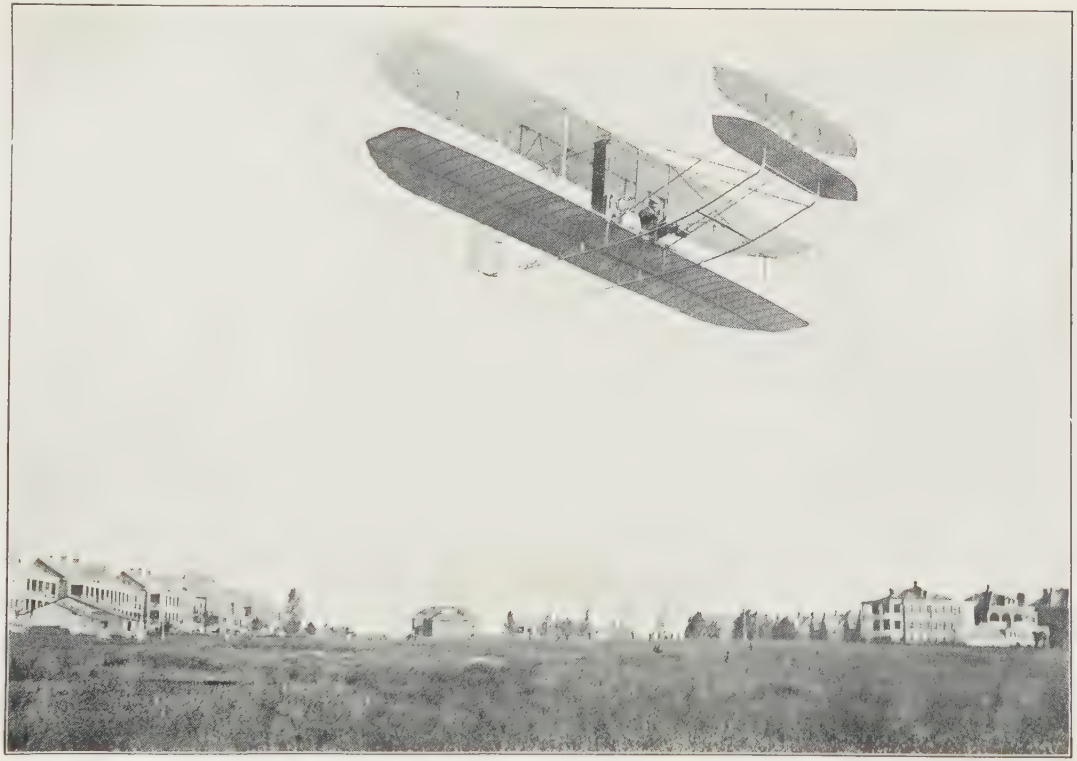
The Farman Aeroplane.

The Farman flying machine has two superposed aerosurfaces 4 feet 11 inches apart, with a spread of 42 feet 9 inches and 6 feet 7 inches from front to rear. The total sustaining surface is about 560 square feet.

A box tail 6 feet 7 inches wide and 9 feet 10 inches long in rear of the main surfaces is used to balance the machine. The vertical sides of the tail are pivoted along the front edges, and serve as a vertical rudder for steering in a horizontal plane. There are two parallel, vertical partitions near the middle of the main supporting surfaces, and one vertical partition in the middle of the box tail. A horizontal rudder in front of the machine is used to elevate or depress it in flight.



WRIGHT BROTHERS' AEROPLANE; DETAILS OF CONSTRUCTION.



WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 9, 1908.

The motor is an eight-cylinder Antoinette of 50 horsepower weighing 176 pounds, and developing about 38 horsepower at 1,050 revolutions per minute.

The propeller is a built-up steel frame covered with aluminum sheeting, 7½ feet in diameter, with a pitch of 4 feet 7 inches. It is mounted directly on the motor shaft immediately in rear of the middle of the main surfaces.

The framework is of wood, covered with canvas. A chassis of steel tubing carries two pneumatic-tired bicycle wheels. Two smaller wheels are placed under the tail. The total weight of the machine is 1,166 pounds. The main surfaces support a little over 2 pounds per square foot. The machine has shown a speed of about 28 miles per hour and no starting apparatus is used.

On January 13, 1908, Farman won the Grand Prix of the Aero Club of France in a flight of one minute and twenty-eight seconds, in which he covered more than a kilometer. It is reported that on October 30, 1908, a flight of 20 miles, from Mourmelon to Rheims, was made with this machine.

The Blériot Aeroplane.

Following Farman's first flight from town to town, M. Blériot with his monoplane aeroplane made a flight from Toury to the neighborhood of Artenay and back, a total distance of about 28 kilometers. He landed twice during these flights and covered 14 kilometers of his journey in about ten minutes, or attained a speed of 52 miles an hour.

The June Bug.

The June Bug was designed by the Aerial Experiment Association, of which Alexander Graham Bell is president. It has two main superposed aerosurfaces with a spread of 42 feet and 6 inches, including wing tips, with a total supporting surface of 370 square feet.

The tail is of the box type. The vertical rudder above the rear edge of the tail is 30 inches square. The horizontal rudder in front of the main surfaces is 30 inches wide by 8 feet long. There are four triangular wing tips pivoted along their front edges for maintaining transverse equilibrium. The vertical rudder is operated by a steering wheel, and the movable tips by cords attached to the body of the aviator.

The motor is a 25-horsepower, 8-cylinder, air-cooled Curtiss. The single wooden propeller immediately behind the main surfaces is 6 feet 2 inches in diameter and mounted directly on the motor shaft. It has a pitch angle of about 17° and is designed to run at about 1,200 revolutions per minute.

The total weight of the machine, with aviator, is 650 pounds. It has a load of about $1\frac{3}{4}$ pounds per square foot of supporting surface. Two pneumatic-tired bicycle wheels are attached to the lower part of the frame.

With this machine, Mr. G. H. Curtiss, on July 4, 1908, won the Scientific American trophy by covering the distance of over a mile in one minute and forty-two and two-fifths seconds at a speed of about 39 miles per hour.

SOME GENERAL CONSIDERATIONS WHICH GOVERN THE DESIGN OF AN AEROPLANE.

The design of an aeroplane may be considered under the heads of support, resistance and propulsion, stability, and control.

Support.

In this class of flying machines, since the buoyancy is practically insignificant, support must be obtained from the dynamic reaction of the atmosphere itself. In its simplest form, an aeroplane may be considered as a single plane surface moving through the air. The law of pressure on such a surface has been determined and may be expressed as follows:

$$P = 2k\sigma AV^2 \sin \alpha \qquad (1)$$

in which P is the normal pressure upon the plane, k is a constant of figure, σ the density of the air, A is the area of the plane, V the relative velocity of translation of the plane through the air, and α the angle of flight.

This is the form taken by Duchemin's formula for small angles of flight such as are usually employed in practice. The equation shows that the upward pressure on the plane varies directly with the area of the plane, with the sine of the angle of flight, with the density of the air, and also with the square of the velocity of translation.

It is evident that the total upward pressure developed must be at least equal to the weight of the plane and its load, in order to support the system. If P is greater than the weight, the machine will ascend; if less, it will descend.

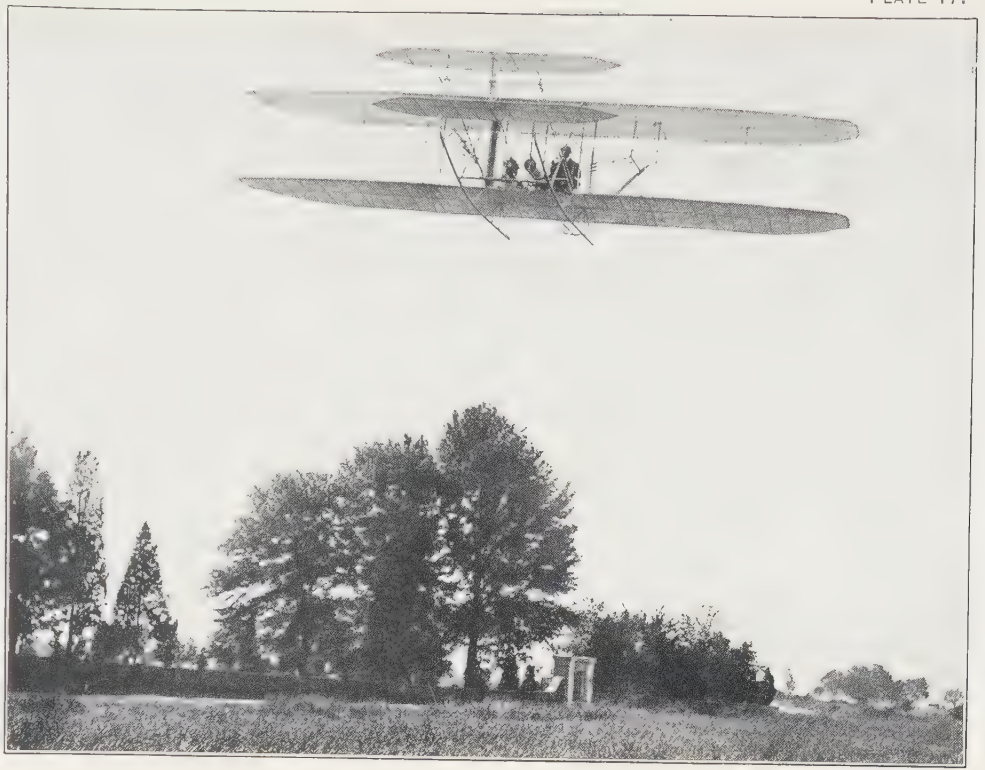
The constant k depends only upon the shape and aspect of the plane, and should be determined by experiment. For example, with a plane 1 foot square $k\sigma = 0.00167$, as determined by Langley, when P is expressed in pounds per square foot, and V in feet per second.

Equation (1) may be written

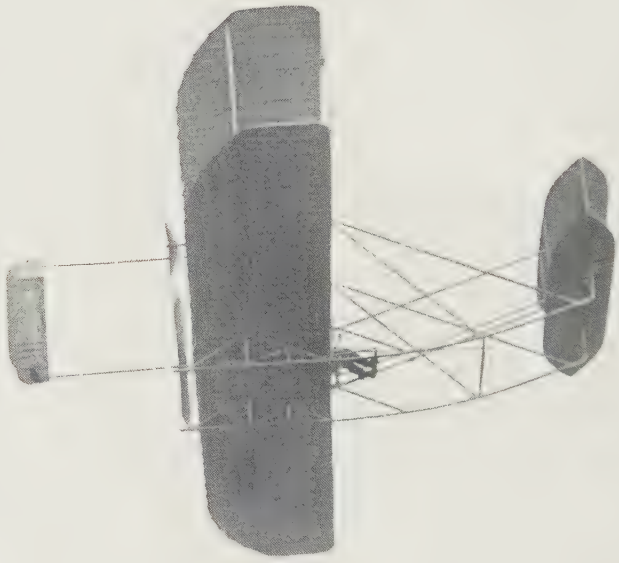
$$AV^2 = \frac{P}{2k\sigma \sin \alpha}.$$

If P and α are kept constant then the equation has the form

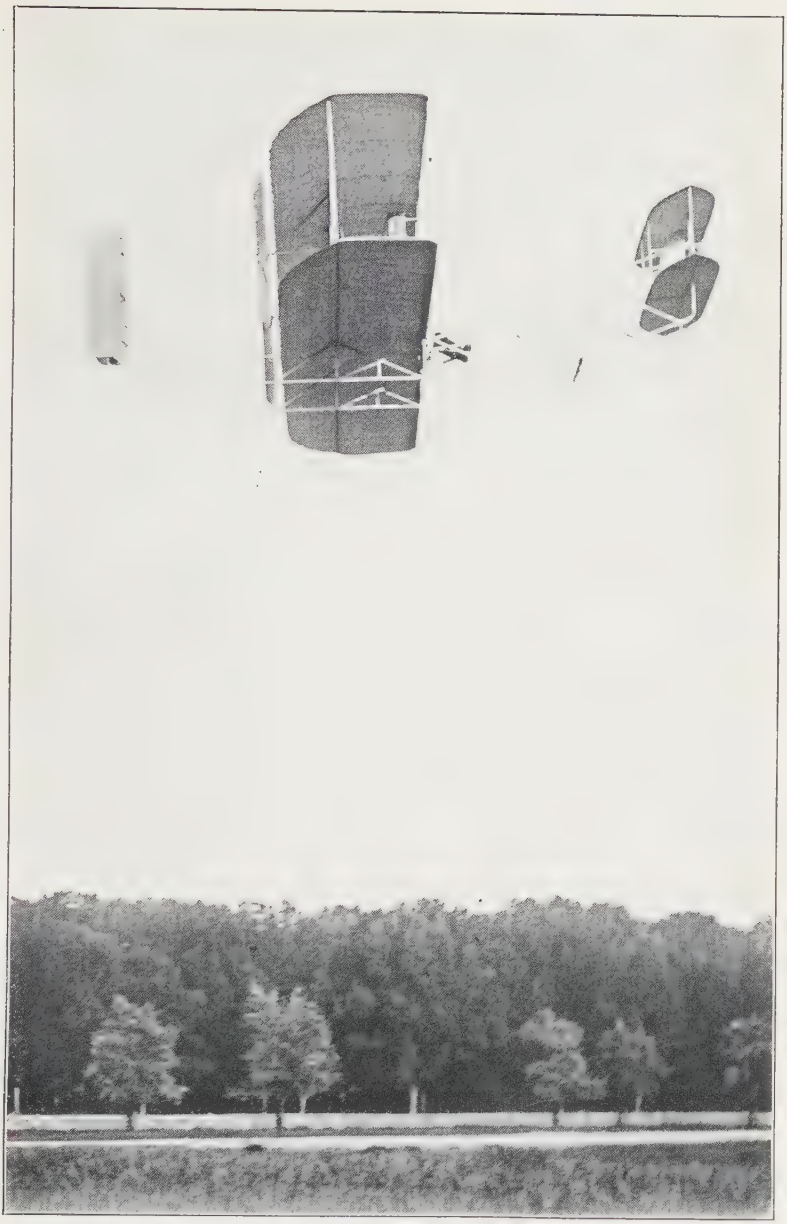
$$AV^2 = \text{constant}. \qquad (2)$$



WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 9, 1908.



WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 12, 1908.



WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 12, 1908.

Time of flight, 1 hour 14 minutes 20 seconds.

WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 12, 1908.

Time of flight, 1 hour 14 minutes 20 seconds.

PRINCIPLE OF REEFING IN AVIATION.

An interpretation of (2) reveals interesting relations. The supporting area varies inversely as the square of the velocity. For example, in the Wright aeroplane, the supporting area at 40 miles per hour is 500 square feet, while if the speed is increased to 60 miles per hour this area need be only $\frac{500}{1.52} = 222$ square feet, or less than one-half of its present size. At 80 miles per hour the area would be reduced to 125 square feet, and at 100 miles per hour only 80 square feet of supporting area is required. These relations are conveniently exhibited graphically.

It thus appears that if the angle of flight be kept constant in the Wright aeroplane, while the speed is increased to 100 miles per hour, we may picture a machine which has a total supporting area of 80 square feet, or a double surface, each measuring about $2\frac{1}{2}$ by 16 feet or 4 by 10 feet if preferred. Furthermore, the discarded mass of the 420 square feet of the original supporting surface may be added to the weight of the motor and propellers in the design of a reduced aeroplane, since in this discussion the total mass is assumed constant at 1,000 pounds.

In the case of a bird's flight, its wing surface is "reefed" as its velocity is increased, which instinctive action serves to reduce its head resistance and skin-frictional area, and the consequent power required for a particular speed.

Determination of k for arched surfaces.—Since arched surfaces are now commonly used in aeroplane construction, and as the above equation (1) applies to plane surfaces only, it is important to determine experimentally the value of the coefficient of figure k, for each type of arched surface employed, especially as k is shown in some cases to vary with the angle of flight α; i. e., the inclination of the chord of the surface to the line of translation.

Assuming α constant, however, we may compare the lift of any particular arched surface with a plane surface of the same projected plan and angle of flight.

To illustrate, in the case of the Wright aeroplane, let us assume

$P = 1{,}000$ pounds = total weight = W.
$A = 500$ square feet.
$V = 40$ miles per hour = 60 feet per second.
$\alpha = 7°$, approximately.

Whence
$$k\sigma = \frac{P}{2AV^2 \sin \alpha} = \frac{1{,}000}{2 \times 500 \times 60^2 \times \frac{1}{8}}$$
$$= 0.0022 \text{ (V = foot-seconds)}$$
$$= 0.005 \text{ (V = miles per hour).}$$

Comparing this value of $k\sigma$ with Langley's value 0.004 for a plane surface V being in miles per hour, we see that the lift for the arched surface is 25 per cent greater than for a plane surface of the same projected plan. That is to say, this arched surface is dynamically equivalent to a plane surface of 25 per cent greater area than the projected plan. Such a plane surface may be defined as the "equivalent plane."

Resistance and propulsion.

The resistance of the air to the motion of an aeroplane is composed of two parts, (*a*) the resistance due to the framing and load; (*b*) the necessary resistance of the sustaining surfaces; that is, the drift or horizontal component of pressure, and the unavoidable skin friction. Disregarding the frame and considering the aeroplane as a simple plane surface, we may express the resistance by the equation

$$R = W \tan \alpha + 2fA \qquad (3)$$

in which R is the total resistance, W the gross weight sustained, α the angle of flight, f the friction per square unit of area of the plane, A the area of the plane. The first term of the second member gives the drift, the second term the skin friction. The power required to propel the aeroplane is

$$H = RV$$

in which H is the power, V the velocity.

Now W varies as the second power of the velocity, as shown by equation (1), and f varies as the power 1.85, as will be shown later. Hence we conclude that the total resistance R of the air to the aeroplane varies approximately as the square of its speed, and the propulsive power practically as the cube of speed.

Most advantageous speed and angle of flight.—Again, regarding W and A as constant, we may, by equation (1), compute α for various values of V, and find f for those velocities from the skin-friction table to be given presently. Thus α, R, and H may be found for various velocities of flight, and their magnitudes compared. In this way the values in Table 1 were computed for a soaring plane 1 foot square, weighing 1 pound, assuming $k\sigma = 0.001$, which is approximately Langley's value when V is in miles per hour.

WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 12, 1908.

Ready for the start. Orville Wright and passenger.

WRIGHT BROTHERS' AEROPLANE, FORT MYER, VA., SEPTEMBER 12, 1908.

Orville Wright and passenger. Time, 9 minutes 6 seconds.

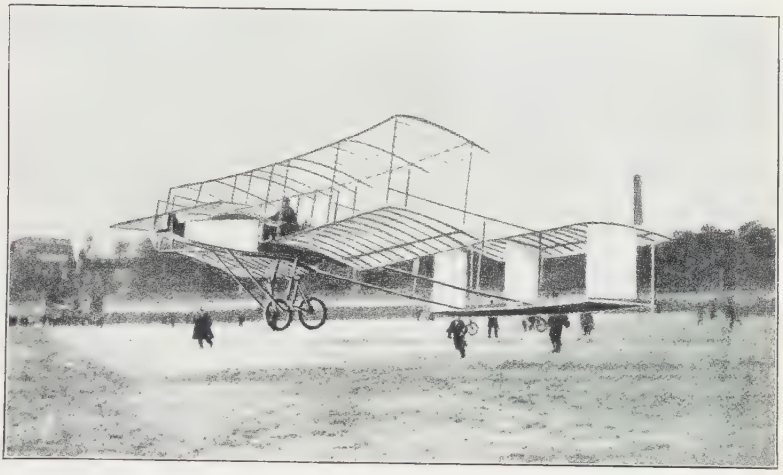


FIG. 1.—FARMAN AEROPLANE.

FIG. 2.—"JUNE BUG" AEROPLANE, HAMMONDSPORT, N. Y.

Aerial Experiment Association.

TABLE 1.—*Computed power required to tow a plane 1 foot square weighing 1 pound horizontally through the air at various speeds and angles of flight.*

Velocity (miles per hour).	Angle of flight.	Computed resistance.			Tow-line power.	Lift per tow-line horse-power.
		Drift.	Friction.	Total.		
	°	*Pounds.*	*Pounds.*	*Pounds.*	*Ft. lb. sec.*	*Pounds.*
30	8.25	0.145	0.0170	0.162	7.13	77.1
35	5.94	.104	.0226	.1266	6.51	84.3
40	4.52	.790	.0289	.1079	6.32	86.7
45	3.55	.0621	.0360	.0981	6.39	86.1
50	2.88	.0500	.0439	.0939	6.89	80.2
60	2.03	.0354	.0614	.0962	8.50	64.7
70	1.47	.0257	.0814	.1071	11.00	50.0
80	1.12	.0195	.1045	.1240	14.56	35.8
90	.88	.0154	.1300	.1454	19.17	28.7
100	.71	.0124	.1584	.1708	25.00	22.0

Column two, giving values of α for various speeds, is computed from equation (1). Thus, at 30 miles per hour,

$$\sin \alpha = \frac{W}{2k\sigma A V^2} = \frac{1}{2 \times .004 \times 1 \times 30^2}$$

whence $\alpha = 8.25°$.

Column three is computed from the term W tan α in equation (3), thus:

$$\text{Drift} = W \tan \alpha = 1 \times \tan 8.25° = 0.145.$$

Column four is computed from the term $2fA$ in equation (3), f being taken from the skin-friction table, to be given presently.

The table shows that if a thin plane 1 foot square, weighing 1 pound, be towed through the air so as just to float horizontally at various velocities and angles of flight, the total resistance becomes a minimum at an angle of slightly less than 3°, and at a velocity of about 50 miles per hour; also that the skin-friction approximately equals the drift at this angle. The table also shows that the propulsive power for the given plane is a minimum at a speed of between 40 and 45 miles per hour, the angle of flight then being approximately 4.5°.

The last column of the table shows that the maximum weight carried per horsepower is less than 90 pounds. This horse load may be increased by changing the foot-square plane to a rectangular plane and towing it long side foremost; also by lightening the load, and letting the plane glide at a lower speed; but best of all, perhaps, by arching it like a vulture's wing and also towing it long side foremost as is the prevailing practice with aeroplanes.

Stability and control.

The question of stability is a serious one in aviation, especially as increased wind velocities are encountered. In machines of the aero

plane type there must be some means provided to secure fore and aft stability and also lateral stability.

A large number of plans have been proposed for the accomplishment of these ends, some based upon the skill of the aviator, others operated automatically, and still others employing a combination of both. At the present time no aeroplane has yet been publicly exhibited which is provided with automatic control. There is little difference of opinion as to the desirability of some form of automatic control.

The Wright aeroplane does not attempt to accomplish this, but depends entirely upon the skill of the aviator to secure both lateral and longitudinal equilibrium; but it is understood that a device for this purpose is one of the next to be brought forward by them. Much of the success of the Wright brothers has been due to their logical procedure in the development of the aeroplane, taking the essentials, step by step, rather than attempting everything at once, as is so often the practice with inexperienced inventors.

The aviator's task is much more difficult than that of the chauffeur. With the chauffeur, while it is true that it requires his constant attention to guide his machine, yet he is traveling on a roadway where he can have due warning through sight of the turns and irregularities of the course.

The fundamental difference between operating the aeroplane and the automobile is that the former is traveling along an aerial highway which has manifold humps and ridges, eddies and gusts, and since the air is invisible he can not see these irregularities and inequalities of his path, and consequently can not provide for them until he has actually encountered them. He must feel the road since he can not see it.

Some form of automatic control whereby the machine itself promptly corrects for the inequalities of its path is evidently very desirable. As stated above, a large number of plans for doing this have been proposed, many of them based on gyrostatic action, movable side planes, revolving surfaces, warped surfaces, etc. A solution of this problem may be considered as one of the next important steps forward in the development of the aeroplane.

III. Hydromechanic Relations.

Some general relations between ships in air and in water.

At the present moment so many minds are engaged upon the general problem of aerial navigation that any method by which a broad forecast of the subject can be made is particularly desirable. Each branch of the subject has its advocates, each believing implicitly in the superiority of his method. On the one hand the adherents of

the dirigible balloon have little confidence in the future of the aeroplane, while another class have no energy to devote to the dirigible balloon, and still others prefer to work on the pure helicopter principle. As a matter of fact, each of these types is probably of permanent importance, and each particularly adapted to certain needs.

Fortunately for the development of each type, the experiments made with one class are of value to the other classes, and these in turn bear close analogy to the types of boats used in marine navigation. The dynamical properties of water and air are very much alike, and the equations of motion are similar for the two fluids, so that the data obtained from experiments in water, which are very extensive, may with slight modification be applied to computations for aerial navigation.

Helmholtz's theorem.—Von Helmholtz, the master physicist of Germany, who illuminated everything he touched, has fortunately considered this subject in a paper written in 1873. The title of his paper is "On a theorem relative to movements that are geometrically similar in fluid bodies, together with an application to the problem of steering balloons."

In this paper Helmholtz affirms that, although the differential equations of hydromechanics may be an exact expression of the laws controlling the motions of fluids, still it is only for relatively few and simple experimental cases that we can obtain integrals appropriate to the given conditions, particularly if the cases involve viscosity and surfaces of discontinuity.

Hence, in dealing practically with the motion of fluids, we must depend upon experiment almost entirely, often being able to predict very little from theory, and that usually with uncertainty. Without integrating, however, he applies the hydrodynamic equations to transfer the observations made on any one fluid with given models and speeds over to a geometrically similar mass of another fluid involving other speeds and models of different magnitudes. By this means he is able to compute the size, velocity, resistance, power, etc., of aerial craft from given, or observed, values for marine craft.

He also deduces laws that must inevitably place a limit upon the possible size and velocity of aerial craft without, however, indicating what that limit may be with artificial power. Applying this mode of reasoning to large birds he concludes by saying that "It therefore appears probable that in the model of the great vulture nature has already reached the limit that can be attained with the muscles as working organs, and under the most favorable conditions of subsistence, for the magnitude of a creature that shall raise itself by its wings and remain a long time in the air."

In comparing the behavior of models in water and air he takes account of the density and viscosity of the media, as these were well

known at the date of his writing, 1873; but he could not take account of the sliding, or skin-friction, because in his day neither the magnitude of such friction for air, nor the law of its variation with velocity, had been determined.

Skin-friction in air.

Even as late as Langley's experiments, skin-friction in air was regarded as a negligible quantity, but due to the work of Doctor Zahm, who was the first to make any really extensive and reliable experiments on skin-friction in air, we now can estimate the magnitude of this quantity. As a result of his research he has given in his paper on "Atmospheric friction" the following equation:

$$f = 0.00000778\ l^{-0.07}\ v^{1.85} \ldots (v = \text{feet per second}),$$
$$f = 0.0000158\ \ l^{-0.07}\ v^{1.85} \ldots (v = \text{miles per hour}),$$

in which f is the average skin-friction per square foot, and l the length of surface.

From this equation the accompanying table of resistances was computed, and is inserted here for the convenience of engineers:

TABLE 2.—*Friction per square foot for various speeds and lengths of surface.*

Wind speed (miles per hour).	Average friction, in pounds per square foot.					
	1-foot plane.	2-foot plane.	4-foot plane.	8-foot plane.	16-foot plane.	32-foot plane.
5	0.000303	0.000289	0.000275	0.000262	0.000250	0.000238
10	.00112	.00105	.00101	.000967	.000922	.000878
15	.00237	.00226	.00215	.00205	.00195	.00186
20	.00402	.00384	.00365	.00349	.00332	.00317
25	.00606	.00579	.00551	.00527	.00501	.00478
30	.00850	.00810	.00772	.00736	.00701	.00668
35	.01130	.0108	.0103	.0098	.00932	.00888
40	.0145	.0138	.0132	.0125	.0125	.0114
50	.0219	.0209	.0199	.0190	.0181	.0172
60	.0307	.0293	.0279	.0265	.0253	.0242
70	.0407	.0390	.0370	.0353	.0337	.0321
80	.0522	.0500	.0474	.0452	.0431	.0411
90	.0650	.0621	.0590	.0563	.0536	.0511
100	.0792	.0755	.0719	.0685	.0652	.0622

The numbers within the rules represent data coming within the range of observation. These observations show that "the frictional resistance is at least as great for air as water, in proportion to their densities. In other words, it amounts to a decided obstacle in high-speed transportation. In aeronautics it is one of the chief elements

of resistance both to hull-shaped bodies and to aero-surfaces gliding at small angles of flight."

Relative dynamic and buoyant support.—Peter Cooper-Hewitt has given careful study to the relative behavior of ships in air and in water. He has made a special study of hydroplanes, and has prepared graphic representations of his results which furnish a valuable forecast of the problem of flight.

Without knowing of Helmholtz's theorem, Cooper-Hewitt has independently computed curves for ships and hydroplanes from actual data in water, and has employed these curves to solve analogous problems in air, using the relative densities of the two media, approximately 800 to 1, in order to determine the relative values of support by dynamic reaction and by displacement for various weights and speeds.

An analysis of these curves leads to conclusions of importance, some of which are as follows:

The power consumed in propelling a displacement vessel at any constant speed, supported by air or water, is considered as being two-thirds consumed by skin-resistance, or surface resistance, and one-third consumed by head resistance. Such a vessel will be about 10 diameters in length, or should be of such shape that the sum of the power consumed in surface friction and in head resistance will be a minimum (torpedo shape).

The power required to overcome friction due to forward movement will be about one-eighth as much for a vessel in air as for a vessel of the same weight in water.

Leaving other things out of consideration, higher speeds can be obtained in craft of small tonnage by the dynamic reaction type than by the displacement type, for large tonnages the advantages of the displacement of type are manifest.

A dirigible balloon carrying the same weight, other things being equal, may be made to travel about twice as fast as a boat for the same power or be made to travel at the same speed with the expenditure of about one-eighth of the power.

As there are practically always currents in the air reaching at times a velocity of many miles per hour, a dirigible balloon should be constructed with sufficient power to be able to travel at a speed of about 50 miles per hour, in order that it may be available under practical conditions of weather. In other words, it should have substantially as much power as would drive a boat, carrying the same weight, 25 miles an hour, or should have the same ratio of power to size as the *Lusitania*.

Motors.—It is the general opinion that any one of several types of internal combustion motors at present available is suitable for use with dirigible balloons. With this type lightness need not be ob-

tained at the sacrifice of efficiency. In the aeroplane, however, lightness per output is a prime consideration, and certainty and reliability of action is demanded, since if by chance the motor stops the machine must immediately glide to the earth. A technical discussion of motors would of itself require an extended paper, and may well form the subject of a special communication.

Propellers.—The fundamental principles of propellers are the same for air as for water. In both elements the thrust is directly proportional to the mass of fluid set in motion per second. A great variety of types of propellers have been devised, but thus far only the screw propeller has proved to be of practical value in air. The theory of the screw propeller in air is substantially the same as for the deeply submerged screw propeller in water, and therefore does not seem to call for treatment here. There is much need at present for accurate aerodynamic data on the behavior of screw propellers in air, and it is hoped that engineers will soon secure such data and present it in practical form for the use of those interested in airship design.

Limitations.—Euclid's familiar "square-cube" theorem connecting the volumes and surfaces of similar figures, as is well known, operates in favor of increased size of dirigibles and limits the possible size of heavier-than-air machines in single units and with concentrated loads.

It appears, however, that both fundamental forms of aerial craft will likely be developed, and that the lighter-than-air type will be the burden-bearing machine of the future, whereas the heavier-than-air type will be limited to comparatively low tonnage, operating at relatively high velocity. The helicopter type of machine may be considered as the limit of the aeroplane when, by constantly increasing the speed, the area of the supporting surfaces is continuously reduced until it practically disappears. We may then picture a racing aeroplane propelled by great power, supported largely by the pressure against its body, and with its wings reduced to mere fins which serve to guide and steady its motion. In other words, starting with the aeroplane type, we have the dirigible balloon on the one hand as the tonnage increases, and the helicopter type on the other extreme as the speed increases. Apparently, therefore, no one of these forms will be exclusively used, but each will have its place for the particular work required. * * *

AVIATION IN FRANCE IN 1908.[a]

By Pierre-Roger Jourdain,
Member of the Aero Club of France, General Secretary of the Aero Club of Vichy.

The science of aviation may be said to have originated with the French. It is not a new science. As far back as 1742 there is authentic record of mechanical flight by man. In that year the Marquis of Bacqueville, 60 years old, hurled himself from his house top, glided a distance of 300 meters, and landed unceremoniously on a laundry boat moored along the banks of the Seine. Later came the isolated experiments by Blanchard (1753–1809) and by Degen, and aviation was for the time forgotten.

Henson, in 1843, and Du Temple, in 1857, constructed the first flying machines of rational design. These embodied in embryo the main features of some of our present machines, yet nothing was accomplished with either of them.

Then came the profitable agitation of the subject aroused in 1863 by Nadar, who, relying on the experiments of Ponton d'Amécourt and of Lalandelle, revolutionized European ideas by his well-known exposition of the science of aerial navigation. Nadar pointed out that up to that time the balloon must be held responsible for the lack of progress in mechanical flight, and that to actually fly it was essential that the apparatus be heavier than air. In his researches he had the support of M. Babinet, member of the institute. Then aviation again dropped from public notice. Although forgotten by the public, several investigators, among them Penaud, de Villeneuve, Tatin, and Marey, were conducting the first series of scientific studies on the flight of birds, which are still consulted with profit. Finally

[a] Conference under the auspices of the association of former pupils of the Faculty of Sciences of Paris, in the large amphitheater of the Sorbonne, December 19, 1908, M. Appell presiding. Translated, with permission, from the Revue Scientifique, Paris, February 13, 1909.

came the experiments by Lilienthal, Maxim, Langley, and Chanute, from 1892 to 1896.

Specifically, what is the problem of aviation? It consists in launching a heavy body from the earth and in maintaining and guiding it in the air through purely mechanical means. Aviation has also been defined as the science of flying with machines heavier than air, as distinguished from aerostation, the science of ballooning, with apparatus lighter than air.

It is the solution of this difficult problem of flying that men have sought for a number of years.

Three different solutions of the problem have been proposed: One is in servile imitation of nature, that represented by the orthopter or wing machine. The second is a purely artificial conception, that of the helicopter or screw machine. The third is that of the aeroplane, which may be considered as a compromise, or a combination of the first two systems.

The wing machine is, as I have stated, a servile imitation of nature. It is equipped with moving wings, and the machine is lifted by the reaction from the flapping of these wings. One of the principal representatives of this type is that designed by Blanchard even before Montgolfier's hot air balloon; and, if rumors may be believed, secret experiments are now being conducted in Belgium with the La Hault type of this machine.

In these wing machines the amount of force upon the air is normal and applied directly, so as to raise the apparatus vertically. It is at once evident that of the two motions in the flapping of the wings, the downward stroke causes the machine to move upward, while the upward stroke rather retards this movement. The attempt has been made to overcome this difficulty by the use of valves in the wings that open when the wing is raised and close when it is lowered. None of these machines, however, has given satisfactory results.

The second type is the helicopter, or screw machine, a purely artificial conception. Paucton was the first to suggest the application of the principle of the screw to aerial navigation, but it remained for de Lalandelle and Ponton d'Amécourt to actually experiment with this system and obtain the first practical results.

The principle of this system is that of a screw turning upon a vertical axis, and it is the reaction of the air during the movement of the screw that should balance or overcome the weight of the apparatus and cause it to rise.

These machines are very complicated. Whenever a force is applied to a medium such as air, there results a reaction equal to the action

first brought to bear. The screw, and consequently the whole machine, sustains from the air upon which it acts, a reaction equal to, but in the direction opposite to, that which it exercises. If we have a screw turning in a certain direction, the whole apparatus, upon the stability of which we rely to force the turning of the screw against the air, will tend to turn in the opposite direction as the result of a reactive force equal to that exercised by the screw. To overcome this tendency the attempt was made to increase the inertia of the machine by attaching vertical planes or surfaces in such a manner as to retard its rotative movement.

But these large surfaced vertical planes are cumbersome and heavy. With laudable persistency investigators have devised a second method more advantageous than the first, which consists in the use of two screws turning in opposite directions, so that the effect of the reaction of the air on one screw is neutralized by the reaction on the other. Such an apparatus is capable only of lifting and sustaining itself in the air; it can not move horizontally. For this movement it must be supplied with a third screw, or propeller, mounted on a horizontal axis. This forms still another complication, for the use of only two sustaining screws is a minimum depending on the weight of the machine. And since the size of the screws is limited by considerations of strength their number must be increased, always in pairs, to four, six, or eight.

M. Cornu in 1907 succeeded in lifting two passengers vertically. To obtain a horizontal movement M. Breguet attached to his machine cloth planes inclined at an appropriate angle, and it was through the reaction of the air from the vertical displacement on these planes that this apparatus was designed to move forward.

Let us now examine the third solution, that of the aeroplane, which, as I have said, is a compromise or a combination of the first two systems.

In the aeroplane the principal parts are comprised in an inclined surface, and it is this inclined surface gliding at a certain speed into the wind that sustains the machine. The total reaction of the air upon this surface resolves itself into two components—the resistance to horizontal advancement and the vertical thrust. These two forces are proportional to the square of the speed of propulsion and the area of the plane surface. Thus, if a given speed is doubled, we bring to bear on a given surface area, a force equal to the square of the force at the initial speed. This is the reason for the efforts to attain a greater speed, a speed which depends upon the power of the engine and screw of motor-propelled machines.

ELEMENTARY THEORY OF AVIATION.

(After M. Armengaud, jr.)

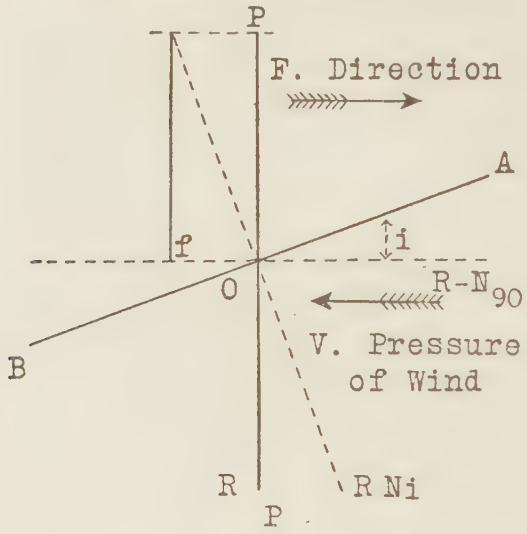


Fig. 1.

R = resistance of air per square meter.
S = sustaining surface.
V = speed, assuming horizontal displacement in calm air.
i = angle of attack.
P = weight to be sustained and driven forward.
f = horizontal component of the resistance or the force opposed to horizontal motion.
P′ = vertical component, or reaction making up the sustaining force, and equal to P.
T = elementary work in the case of a plane.
$\mathfrak{T}$ = total work.
K = coefficient of resistance of the air.

LAW OF VARIATIONS OF THE RESISTANCE OF THE AIR FOLLOWING THE ANGLE OF ATTACK.

N_i = Resistance of the inclined plane making the angle i.
N_{90} = Resistance of the perpendicular plane to advancement.

$$\frac{N_i}{N_{90}} = \begin{cases} \sin^2 i & \text{(Newton and Euler).} \\ \sin i & \text{(Marey).} \\ \dfrac{2\pi \sin i}{4+\pi \sin i} & \text{(Rayleigh).} \\ \dfrac{(4+\pi)\sin i}{4+\pi \sin i} & \text{(Gerlach).} \\ \dfrac{2 \sin i}{1+\sin^2 i} & \text{(Duchemin).} \\ \sin i\,[a-(a-l)\sin^2 i] & \text{(Renard).} \end{cases}$$

FORMULÆ.

In the case of a narrow plane.

$R = KSV^2$ (plane perpendicular to V).
$R_i = KSV^2 \sin i$ (inclined on V).

$P = R_i \cos i = KSV^2 \sin i \cos i$ or $\frac{1}{2} KSV^2 \sin 2i$.

$$V^2 = \frac{2P}{KS \sin 2i}$$

$f = R_i \sin i = KSV^2 \sin^2 i$.

$$f = \frac{P^2}{KSV^2 \cos^2 i} = P \tan i.$$

$T = fV = KSV^3 \sin^2 i$.

$$T = \frac{KS \times 4P^2 \sin^2 i}{\sqrt{K^2 S^2 \sin^2 2i}}$$

Whence:

$$T = \frac{P^2}{KSV \cos^2 i}$$

By eliminating V we have—

$$T = \frac{P}{\cos i} \sqrt{\frac{P}{KS} \tan i}$$

In case of the aeroplane.

F=total force of movement.

f'=force required to overcome resistance to advancement.

K′=coefficient of resistance of the air to advancement.

S′=ideal surface corresponding to framework, with motor, rigging, aviator and equipment.

$f' = K'S'V^2$.

$F = f + f'$.

$\mathfrak{C} = (f + f')V$.

$$\mathfrak{C} = \frac{P^2}{KSV \cos^2 i} + K'S'V^3.$$

To secure the minimum value of $\mathfrak{C}$ the derivatives may be used with the following result:

$$\frac{d\mathfrak{C}}{dV} = -\frac{P^2}{KSV^2 \cos^2 i} + 3K'S'V^2 = 0.$$

Whence: $f = 3f'$.

Propulsion creates and accompanies sustenance.

In this connection I wish to make clear one frequently disputed point in regard to aerial navigation—that is, as to the importance of the part played by the wind. As far as the aeroplane is concerned this is reduced to a minimum. As a matter of fact, the governing feature of an aeroplane is the speed of the machine itself against the air. If the air produces a pressure that is negative, or of no effect at all, it will influence only the horizontal displacement of the machine; the vertical displacement will depend always on the speed of the aeroplane itself. If the speed of the wind blowing against the machine is equal to the machine's own speed, the aeroplane will rise but will not advance; it will fly and yet be stationary in the air. If there is no opposing wind, the machine will move horizontally at a rate equal to its own speed; if the wind blows in the direction the machine is going, the rate of advance of the aeroplane will be the sum of its own speed and of the speed of the wind.

This solution of the problem is, a priori, better than that offered by the wing or screw machines. In fact, in applying the principle of the inclined plane, instead of lifting directly the total weight of the machine, it is necessary to bring into play forces proportional only to one-eighth or one-fifth of this weight.

I said this machine was in a way a compromise or combination. We find in it, in fact, both an imitation of nature and an intervention of artificial contrivances.

If we observe the great soaring birds, such as the vulture and the sea gull, we see them often remain motionless in the air, their wings stretched, or even glide forward without flapping their wings. This is true only under certain circumstances, and is what we call "le vol a la voile" (sailing flight). It is really an optical illusion, for if we substitute for our eyes a cinematograph or instruments of study, such as those designed by Marey, we should be able, so to speak, to dissect the flight of the bird, and we should find that the tips of the wings are slightly moved from time to time. These movements of the tips of the wings are supplanted in the machine by the screw propeller. The propeller furnishes the same propulsion as that secured by the wings of the bird. Consequently, a machine constructed in this manner, with a plane suitably inclined, and a system of motor propulsion, should be able to lift itself in the air. But to lift itself is not enough; it should be capable of sustaining itself and of being guided; and there occurs the question, would such a machine equipped merely in this manner maintain itself in the air? No, it would not, for the air is essentially mobile; the wind, even when it seems most constant, is made up of pulsations, of layers of different speeds, pressures, and densities. So, considering merely its resistance to the advance of the machine, since this resistance varies in proportion to the density of the medium, the aeroplane, subjected to these incessant fluctuations of the wind, will tend momentarily to change its state of equilibrium; it will undergo various movements, forward and backward, to the right and to the left, and will doubtless capsize. Furthermore, the steadiest atmospheric winds are filled with counter currents. If there is one principal current flowing in a definite direction, together with it are to be found accessory currents, oblique winds, winds rising from eddies caused by obstructions of the ground, and the uneven slopes of the earth, trees, and houses. These currents striking the large planes on the side would tend to capsize the machine.

There are three movements to be guarded against in an aeroplane: pitching, rolling, and a tendency to veer unexpectedly. We must be able to guide the machine at will. This question of longitudinal and transverse equilibrium has been a source of trouble to our aviators for a long time. And during the present year, 1908, aviators have

been divided into two schools, those who favor the system of governed longitudinal equilibrium and those who prefer automatic longitudinal equilibrium.

The school of governed equilibrium is made up of those who rely upon the pilot of the machine to overcome by constant maneuvering any movements out of the line of perfect balance. Take for instance the pitching. This movement, forward or backward, so familiar on shipboard would tend to make the machine shoot up or down. To overcome this pitching a movable horizontal rudder is used. This part of the apparatus is composed simply of a miniature reproduction of the sustaining plane and is usually placed in front quite a distance from the center of gravity. This plane is pivoted on an axis and can be inclined at the will of the pilot. If the machine tends to pitch downward, the pilot, by merely increasing the angle of the plane, lifts the front part of the machine; the whole apparatus follows this movement and assumes a horizontal position, which is the position of equilibrium.

To overcome rolling, the machines, even those whose longitudinal balance is a governed one, generally have a certain arrangement which we might call automatic, embodied in the angle made between the two planes following the longitudinal axis of the machine. This angle reduces to a certain extent the amplitude of the oscillation. To overcome the rolling movement the aviator acts exactly as in the case of pitching; he inclines the wing on one side or on the other. He can incline either the whole wing by warping it, or perhaps only a portion of it, the tip of the wing only being made movable. The governing motion is the same; if the machine begins to fall to the right or to the left, it is necessary only to give a greater inclination to the wing on the side toward which the aeroplane is falling in order that it may right itself.

To prevent unexpected veering, there is a tail in the form of a cross which acts like the feathers of an arrow and insures true direction.

A machine of governed equilibrium thus composed of a plane and a system of motor propulsion and of an arrangement to avoid pitching, rolling, and veering can rise and maintain itself in the air, but it is a dangerous machine. To follow the very happy expression of M. Painlevé, it is "a veritable thoroughbred of the air" which needs a jockey with plenty of nerve. The principal examples of this type are the Wright, the Blériot, and the Robert Esnault-Pelterie machines. The Wright machine, however, although of governed equilibrium, differs from the ideal type that I have just pictured in that it is a biplane.

The real difference between a monoplane and a biplane, and the reason why some aviators prefer the latter to the former is because,

with equal surface areas, the biplane is much easier to construct, especially when, as is the practice to-day, rigid surfaces are sought. The biplanes are also more compact than the monoplanes, and permit the use of an equal area of wing surface with only half the spread. Furthermore, equilibrium is preserved much more easily in a biplane. The underlying principles of these phenomena have not yet been completely explained. I shall confine myself to recalling the ideas of Chanute on the cellular forms (biplanes in compartments), ideas apparently well founded. Chanute holds that an air current at high speed confined by the walls or planes of the apparatus offers great resistance to any lateral displacement. It is somewhat similar to the action of the gyroscope, or rather the action is similar to that in a hose from which water is rushing out at a great speed and which is difficult to move. The same principles govern aeroplanes.

Another detail: We have said that aeroplanes are sustained in the air by means of plane surfaces. This is not absolutely accurate, since the sustaining surfaces, viewed in section, show a slight curve. This curve is the result of experiment. It was found that the best flights were obtained when the wings cut the air squarely with their front edges, and when the resistance of the air was used on surfaces inclined gradually in greater degree. Air is so complex a medium and one that we really understand so little that it is only by long and careful experiment that the proper curve of the wings has been determined. The Wright brothers and the Voisin brothers spent several years determining this question. The Voisins experimented with a powerful electric fan, capable of generating a very swift current of air, in front of which they placed linen surfaces mounted on frames with various curves. They weighted these and then measured the reaction of the air current on the surfaces. This method of experiment led them to select the degree of curve adopted on all their machines, particularly those for Delagrange and Farman.

Let us now examine the working of the Wright machine. This machine is of the type whose balance is governed by the pilot. The aviator has in his hands two levers. The left one controls the front balancing planes, or horizontal rudder, and this lever is constantly in motion. They are movements of very short amplitude (35 centimeters forward and 35 centimeters backward, a total amplitude of only 70 centimeters), and that is sufficient to govern the pitching tendencies of the machine. The operation of this requires an attention so close that the least slip would be fatal. It is similar to operating the handle bars of a bicycle, moving to the right or left to retain the balance. The right-hand lever controls the vertical rudder and the warping of the wings. If the machine leans to one side, the operator increases the inclination of the wing on that side and this rights his machine. The simultaneous movement of the rear

vertical rudder prevents the apparatus from changing its direction, as it would tend to do on account of the greater resistance endured by the wing that is warped.

Great fears of fatalities were expressed when experiments in aviation were first undertaken, and I have frequently heard well-meaning persons say: "But there is no future for aviation, because it is so dangerous. You can rise, but you can not descend; you may ride in a machine sustained in the air only by virtue of its great speed. To descend, you must slow down, and since the machine will no longer be sustained in the air, you will fall. Even though you are flying only at a moderate height a catastrophe will surely result. If, on the other hand, by using your horizontal rudder, you should approach the earth, your speed still being 70 or 100 kilometers an hour, when you reach level ground your aeroplane will come in violent contact with the earth, as an automobile would smash into a wall. In any case there would be a catastrophe."

Experience has proven the falsity of these fears. Neither one nor the other of these methods of descent is relied on exclusively. The angle of inclination of the planes is diminished at the same time that speed is lessened, and thus descent is made gradually, until at the last moment, with a slight luff up in the air, the machine alights gently, like a bird, on the ground.

From the statements of M. Painlevé these landings have been quite sure, quite gentle, and at the same time much more easily accomplished than certain balloon landings of which I bear sad recollections.

The second school of experimenters, those who prefer automatic longitudinal equilibrium, has as its principal exponents the Voisin brothers, two men who may truly be ranked among the creators of the science of aviation in France. The followers of this school have taken upon themselves to produce a machine which by its form alone will be stable and will automatically retain its position of equilibrium. They have attempted to realize this ideal so far as longitudinal equilibrium is concerned by the great longitudinal spread they have given to their machines. To secure transversal equilibrium they have utilized quite happily the ideas of Chanute and Hargrave, embodying the use of compartments.

Santos Dumont, first of all, had an apparatus built composed of six sustaining compartments and one compartment for steering and balancing, but the large number of vertical sides was superfluous, for these serve only to make the machine more stable and do not aid in sustaining it; consequently they are dead weight and useless. This school has retained the general idea of Santos Dumont, but has greatly simplified it. For instance, the principle of the compartment is still found in the Voisin aeroplane, but the compartment is reduced to useful dimensions. We likewise find the characteristic balancing

compartment, the question of the surface area of which is an important one. As in the Santos Dumont type, it is placed well to the rear of the center of gravity, but it is fixed. It would appear that in this class of machines there is secured perfect automatic stability. There are no lateral oscillations. Even at speeds of 70 kilometers an hour the balance remains perfect, since speed itself enhances the stability. Some experimenters, however, still object that the compartment offers a great resistance to the turning of the machine.

In this connection I beg leave to recall the following incident:

Wright is not the only aviator who has made flights with a fellow-passenger. French aviators have carried passengers on several occasions. Farman in particular, at Ghent, made a flight of 1 or 2 kilometers with M. Archdeacon, vice-president of the Ligue aérienne. At Mourmelon Farman repeated this exploit in company with M. Painlevé, although in this case, owing to lack of room, M. Painlevé hung onto the frame and, as he says, nearly on M. Farman's back. In spite of the abnormal position of the passenger, however, the machine preserved a perfect equilibrium.

It is much easier to manage this machine than the one whose equilibrium is controlled, since we have here only the front balancing planes and the vertical rudder to manipulate. There are no levers, but a simple automobile steering wheel moving in two directions —one of rotation, which governs the vertical rudder, and a sliding forward and backward in a groove of the whole steering gear to govern the front horizontal rudder. There is nothing to do when sailing straight ahead, and it is necessary to use the balancing planes only to rise. To descend, one slows the engine.

This is a theoretical demonstration. In actual practice those who have managed these machines have certainly evidenced great coolness and have accomplished a very delicate task. The delicacy of the task is caused chiefly by the poor action of our present-day motors. As soon as the ideal motor is attained the French aviators may secure as satisfactory results as the Americans. It is hardly probable that we shall witness any agreement between the two schools of aviators. In fact, those who favor governed equilibrium have realized a machine whose flight is analogous to that of a bird, while those who prefer automatic equilibrium are arriving nearer the form of flight of an arrow. Each class of experimenters has striven toward a different ideal, and each has secured a satisfactory result. One class should not be criticised to the detriment of the other, but both should be praised without reserve.

The Wrights and the Voisin brothers are not the only aviators, for to-day in France they are so numerous that it is impossible here to name them all. New experimenters come to the front daily, each filled with laudable enthusiasm. Certain names, however, force them-

selves upon our attention: That of M. Robert Esnault-Pelterie, well known for his monoplane with warpable wings, and for his excellent R. E. P. motor, and also the names of the untiring Blériot, of Gastambide, of Pischoff, and of Zens.

Among those experimenting with biplanes I may mention Delagrange, Farman, Ferber, who with a 1904 machine nevertheless in 1908 won the third prize for the 200-meters contest at Issy-les-Molineaux, Goupy with his triplane, and finally Moor-Brabazon, in whom should be placed the greatest confidence.

The balance sheet for the year 1908 shows great advancement. It was only on January 13 that the record for a kilometer was established by Farman at Issy-les-Moulineaux, in one minute and twenty-eight seconds. On March 21 he beat his record for 2,004 meters in three minutes and thirty-nine seconds. Delagrange, on April 11, at Issy, covered 3,925 meters in six minutes and thirty seconds. Then he went to Italy and twice in succession—on May 30 and June 22—flew for a quarter of an hour. He returned to France, and after a well-earned period of rest, during which Farman in his turn broke the record for a quarter of an hour (prix Armengaud, in July), he covered—on September 6, at Issy—24,125 meters in twenty-nine minutes, fifty-three and three-fifths seconds. How barely he missed a half hour!

Delagrange is a veteran aviator. He had his machine built in 1906. On three occasions he has made flights of a quarter of an hour, even before Farman, a half an hour at Issy, and since then he has on three occasions flown for half an hour, twice breaking Wright's record, when Wright lengthened the time of his flights.

Wilbur Wright, as is well known, began his flights in France in the middle of the summer of 1908, and in his first trials proved himself a master. It is true that he has experimented a long time, but we should bow before the commendable spirit he has shown and admire his perseverance and courage. More recently Wright flew for two hours, covering more than 100 kilometers.

The greatest honors at the end of the year 1908 will probably not go to French machines, but they have accomplished so much, and have made such rapid progress that we can well have confidence in them. Delagrange covered 24,125 meters and Farman 27,000. We may say, in general, especially since the two admirable flights of Farman and Blériot, that aviation has now become a practical science.[a]

[a] Since the first publication of this paper our prophecies have been amply fulfilled. Although the Voisin biplanes have not succeeded in beating the Wright records, they have at least proved their worth in daily flights varying from 15 to 50 kilometers. The trials of Santos Dumont in his new small monoplane, La Libellule, should also be mentioned, as well as the remarkable flights

There are still, to be sure, certain important questions to be settled, among others that of proper motors, a subject in which automobile manufacturers have not as yet taken special interest. More attention is now, however, being paid to motors in France, for the advent of the motor used by the Wrights has roused us from our apathy. Thus far we have only seen at work the Antoinette and R. E. P. motors. Renault has built an air-cooled motor which still needs certain improvements. The Dutheil, Chamers, and Anzani motors are also deserving of mention.

Finally, at the exhibition this year there was opportunity to examine some new models, which in principle seem interesting, but of which nothing can be said until we have seen them actually work in the air. At present the motor question remains to be settled, and surely will be in 1909. It is the weak point in French flying machines. If a machine can fly for 24 kilometers, with a good motor there is no reason why it should then stop, unless it be to renew the supply of fuel, oil, or water. Our motors, however, so often fail through a tendency to miss the spark, or through the breaking of a valve, or the heating of a bearing. As soon as our motors for flying machines are as perfect as those used in present-day automobiles, we shall be able to fly at will.

And this is not all; we should likewise secure a more efficient use of sustaining surfaces. We should keep constantly in mind, following the advice of M. Tatin, the fact that the aeroplane is a projectile, and should strive in every possible way to decrease resistance to progress through the air. In the aeroplane of Santos-Dumont, built in 1906, there was used a motor of 100 horsepower, Voisin had one of 50 horsepower, Robert Esnault-Pelterie one of 35 horsepower, and Wright's engine is about the same power. Messrs. Koechlin and Pischoff have succeeded in lifting a monoplane and its aviator with a motor of only 16 horsepower. These men are now building in their shops an aeroplane which should fly with a 12-horsepower motor. We can not, however, be certain that it will rise, though the principle is correct.[a] At any rate, it seems probable that the aeroplanes of the future will be driven by motors of not more than 20 horsepower.

The use of such high power is at present not advantageous, for the propellers are very difficult to construct, and they undergo a very fast rotation at speeds generating a centrifugal force that occasionally

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in May, 1909, at Chalons, of Latham, who, with his very successful monoplane Antoinette, from the Levavasseur shops, accomplished flights of over an hour's duration, at an average speed of 80 kilometers an hour, during rain storms and heavy winds. His machine, of 50 horsepower, and carrying one or two passengers, is the most efficient machine we now have. Blériot at the present time is trying out a machine for four passengers (June, 1909).

[a] Since been tried at Jurisy without great success (June, 1909).

plays havoc with them. The circular traction, even in a light-weight propeller may be enough to shatter it or to tear out one of its blades. On the other hand, this circular traction gives a great rigidity to the materials used, inasmuch as the speed of rotation, being considerable, permits the use of propellers of very thin wooden blades, or of sheets of aluminum so thin that at rest they are actually supple.

M. Chauvière has specialized in the study of this phase of the question. He has built propellers of turned wood, that are quite novel.

This, however, is not the whole problem. At present we are using propellors with short pitch and a high speed, which do not give good results. Judging from our experience with steamships, this is because the short pitched propeller, turning too rapidly, creates a neutral space or vacuum in front of it and therefore does not take full hold of the medium in which it turns. In water it turns in its place without hardly advancing; this is what is called in French the phenomenon of "cavitation." If the pitch be increased, there is generated a reversing force which can not be neglected even with the great inertia of aeroplanes. On the other hand, without altering the pitch of the propeller the efficiency may be enhanced by increasing its diameter, and the consequent volume of air upon which it acts. But here we encounter still another difficulty that arises from the necessary position of the driving apparatus in the flying machine, a position determined by other mechanical considerations, and this difficulty is embodied in the fact that a propeller's diameter must be so limited that it will not touch the earth when the machine is on the ground.

M. Voisin, who is as well informed as anyone on this subject, has mentioned having noticed in single long-pitched propellers, a partial elimination of the reversing force by the reaction of the spiral of air on the posterior compartment of the aeroplane; but nevertheless there is a marked tendency among aviators, which will probably be realized during the year 1909, to use two long-pitched propellers turning slowly.

To come into popular use, the aeroplane should satisfy three necessary conditions. It should be easy to manage, it should not be too expensive, and finally it should be of some actual service.

We may already say that the machines are not extremely difficult to manage, and that, therefore, is not a condition at which we should stop. M. Delagrange is a sculptor; he had never had experience in aviation and yet he quickly attained very satisfactory results. And, if M. Voisin is to be believed, M. Moor-Brabazon made even more remarkable a debut.

Apprenticeship must certainly be longer in the Wright machine. Mr. Wright has undertaken to teach pupils in three months. One of

these pupils, the Comte de Lambert, now understands the working of the apparatus, but always makes his flights in company with Wright, who has not yet dared let him fly alone.[a] It is true that with this type of machine, there must be accuracy of manipulation out of the ordinary to avoid ever-possible accidents. It is to be noted also that the Wright machines have not yet flown elsewhere than over open fields.

As to the cost of the machines, it is at once evident that aeroplanes will be much less expensive than automobiles, for all that an aeroplane needs are surface areas of cloth or of aluminum, a motor, and a propeller. There are no complicated gears made of special steel, for changing the speed and the differential, and there are no expensive pneumatic tires.

A machine of the Wright and Voisin model now costs 20.000 francs, or about $4,000, but this price may be lowered. Competition will contribute to reduce the cost and we already have manufacturers who undertake to furnish machines to be delivered after trial for 5,000 francs, or $1,000. I believe that this will be the common price for most aeroplanes in the future. In order, however, that aeroplanes may be of reasonable cost, there must be a demand for them, and to create a demand there must be a need for them.

From now on, from the point of usefulness, it is evident that flying machines will render extraordinary service. They will permit direct and rapid transportation anywhere, and one need no longer hesitate to visit lands that to-day are difficult of access.[b] * * * Direct transportation is evident for there are no obstacles in the way; but as to the possible speeds to be attained, that is an open question.

It is certainly possible to obtain very great speeds with an aeroplane. The action of an illimitable force, that of gravity, is at our disposal as soon as the machine is lifted above the ground, and it is always possible to convert into speed the accumulated potential energy, which is proportional to the weight of the machine and the altitude attained.

At the present time the machines do not rise high enough to apply this method of conversion of power. They move forward only through the speed of their propellers. Blériot has thus reached 76 kilometers an hour, and Farman 78 kilometers an hour. These are medium speeds. Blériot has attained on certain occasions speeds greater than 100 kilometers an hour. During the year 1909 we shall certainly realize the speed of 200 kilometers an hour, and ten years

[a] Lambert has since flown perfectly alone. Tissandier is a master and has flown for more than an hour; Capt. de Girardville as well, and Delagrange is learning.

[b] Hubert Latham is learning aviation to explore Africa.—June, 1909.

from now 300 kilometers may be attained. These figures[a] are those of M. Painlevé, member of the Academy of Sciences.

There remains to be considered one other important question. It is not enough that machines be inexpensive, for if there be too great risk to safety people will not make use of them. There must be a certain degree of security. I have heard it said: "The aeroplane has made trips all right, but you are at the mercy of your motor. What will happen if your motor fails to spark, a thing which is possible at any moment? Suppose you are flying over a city, what would you do?" The aeroplane, say some persons, should therefore fly only above rivers, plains, and highways. What interest would there be under such limitations?

As a matter of fact, if the motor stops accidentally, the aeroplane does not fall; it descends as I have said, along the line of an inclined plane, and the angle at which it will descend depends largely on the perfection of the machine and the skill of the pilot. We can admit, generally, that the ratio of the height of the fall to the course covered, measured on a horizontal projection is about 1 to 7, and within a year the ratio of 1 to 10 will surely be attained. Thus the aeroplane, stopped at a height of 100 meters, has at least five or six hundred meters to descend in, not only directly in front but to the right or the left. The machine will therefore be in the center of a circle of at least a kilometer in diameter. It would be quite extraordinary if a suitable place to land could not be found within such limits. (I do not include the hypothesis of soaring, which is beyond the scope of this discussion.) The answer simply is, that if there is fear of a failure of the motor in crossing over cities one should keep at a reasonable height. * * *

[a] Not yet confirmed by experiments.—June, 1909.

WIRELESS TELEPHONY.[a]

[With 20 plates.]

By R. A. Fessenden.[b]

PREFACE.

The discussion of the theory, practical operation, and possibilities of wireless telephony is facilitated by first briefly considering the history of the development of wireless signaling generally.

BRIEF HISTORY OF THE DEVELOPMENT OF WIRELESS SIGNALING.

Introduction.—In preparing this note it has been considered best, for the sake of accuracy, to refer to published results, such as scientific articles or theses or patent specifications. For the sake of brevity, references to work done in repetition of previously published work have as a rule been omitted. So far as possible, the expression of personal opinion has been avoided in this section of the paper, the object being to gather together in concise form the facts known in regard to the development of the art. With the exception of Munk's original paper, which could not be obtained, all references have been verified by consulting the original publications, a work of some labor, and if any omissions or mistakes have been made, data for their correction will be much appreciated.

Origin and Development of Old or Damped Wave-coherer Method (period 1838–1897).

Joseph Henry, to whose work the development of wire telegraphy owes so much, was the first (1838–1842) to produce high frequency

[a] Copyright, 1908, by A. I. E. E. Reprinted, by permission, from Proceedings of the American Institute of Electrical Engineers, Vol. XXVII, No. 7, July, 1908, New York.

[b] A paper presented at the Twenty-fifth Annual Convention of the American Institute of Electrical Engineers, Atlantic City, N. J., June 29, 1908.

electrical oscillations, and to point out and experimentally demonstrate the fact that the discharge of a condenser is under certain conditions oscillatory, or, as he puts it, consists "of a principal discharge in one direction and then several reflex actions backward and forward, each more feeble than the preceding until equilibrium is attained."[a]

This view was also later adopted by Helmholz,[b] but the mathematical demonstration of the fact was first given by Lord Kelvin in his paper on "Transient electric currents."[c]

In 1870 Von Bezold discovered and experimentally demonstrated the fact that the advancing and reflected oscillations produced in conductors by a condenser discharge gave rise to interference phenomena.[d]

Profs. Elihu Thomson and E. J. Houston in 1876 made a number of experiments and observations on high frequency oscillatory discharges.[e]

In 1883 Professor Fitzgerald suggested at a British Association meeting[f] that electromagnetic waves could be generated by the discharge of a condenser, but the suggestion was not followed up, possibly because no means were known for detecting the waves.

Hertz[g] discovered a method of detecting such waves by means of a minute spark-gap, and before March 30, 1888, had concluded his remarkable series of researches, in which for the first time electromagnetic waves were actually produced by a spark-gap and radiating conductor and received and detected at a distance by a tuned receiving circuit.

Hertz changed the frequency of his radiated waves by altering the inductance or capacity of his radiating conductor or antenna, and reflected and focused the electromagnetic waves, thus demonstrating the correctness of Maxwell's electromagnetic theory of light.

Lodge later in the same year read a paper on the "Protection of buildings from lightning,"[h] before the Society of Arts, in which he described a number of interesting experiments on oscillatory discharges.

Great interest was excited by the experiments of Hertz, primarily on account of their immense scientific importance. It was not long, however, before several eminent scientists perceived that the property

[a] Scientific writings of Joseph Henry, Smithsonian Institution.

[b] Helmholz, "Erhaltung der Kraft," Berlin, 1847.

[c] Kelvin, Philosophical Magazine, June, 1853.

[d] Von Bezold, Poggendorff's Annalen, 140, p. 541.

[e] Journal Franklin Institute, April, 1876.

[f] Fitzgerald, "On a method of producing electromagnetic disturbances of comparatively short wave lengths." Report of British Association, 1883.

[g] Hertz, "Electric waves."

[h] Lodge, Society of Arts, 1888.

possessed by the Hertz waves of passing through fog and material obstacles made them particularly suitable for use for electric signaling.

Prof. Elihu Thomson, in a lecture delivered at Lynn, Mass., on "Alternating currents and electric waves," in 1889, suggested this use.

Sir William Crookes in the Fortnightly Review for February, 1892, discussed the matter in some detail. I quote his statement in full, as it shows what a clear conception he had of the possibilities and obstacles to be overcome:

Here is unfolded to us a new and astonishing world, one which it is hard to conceive should contain no possibilities of transmitting and receiving intelligence. Rays of light will not pierce through a wall, nor, as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wave length of which I have spoken will easily pierce such medium, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables, or any of our present costly appliances. Granted a few reasonable postulates, the whole thing comes well within the realms of possible fulfillment. At the present time experimentalists are able to generate electrical waves of any desired wave length from a few feet upward, and to keep up a succession of such waves radiating into space in all directions. It is possible, too, with some of these rays, if not with all, to refract them through suitably shaped bodies acting as lenses, and so direct a sheaf of rays in any given direction; enormous lens-shaped masses of pitch and similar bodies have been used for this purpose. Also an experimentalist at a distance can receive some, if not all, of these rays on a properly constituted instrument, and by concerted signals messages in the Morse code can thus pass from one operator to another. What, therefore, remains to be discovered is: Firstly, simpler and more certain means of generating electrical rays of any desired wave length, from the shortest, say of a few feet in length, which will easily pass through buildings and fogs, to those long waves whose lengths are measured by tens, hundreds, and thousands of miles; secondly, more delicate receivers, which will respond to wave lengths between certain defined limits and be silent to all others; thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors, by the help of which the sensitiveness of the receiver (apparently the most difficult of the problems to be solved) would not need to be so delicate as when the rays to be picked up are simply radiating into space in all directions and fading away according to the law of inverse squares.

I assume here that the progress of discovery would give instruments capable of adjustment by turning a screw or altering the length of a wire, so as to become receptive of wave lengths of any preconcerted length. Thus, when adjusted to 50 yards, the transmitter might emit, and the receiver respond to, rays varying between 45 to 55 yards and be silent to all others. Considering that there would be the whole range of waves to choose from, varying from a few feet to several thousand miles, there would be sufficient secrecy, for curiosity the most inveterate would surely recoil from the task of passing in review all the millions of possible wave lengths on the remote chance of ultimately hitting on the particular wave length employed by his friends whose correspondence he wished to tap. By "coding" the message even this remote chance of surreptitious straying could be obviated.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within the grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation into those of sober fact. Even now, indeed, telegraphing without wires is possible within a restricted radius of a few hundred yards, and some years ago I assisted at experiments where messages were transmitted from one part of a house to another without an intervening wire by almost the identical means here described.

The statement in the last paragraph of the quotation refers to the work of Prof. David E. Hughes.[a]

Professor Dolbear also suggested the same thing in an article in Donahoe's Magazine, March, 1893.

In fact, the idea of using Hertzian waves for wireless telegraphy seems to have been quite widespread in the years immediately following Hertz's publications.

Fairly efficient means of generating electromagnetic waves of any desired length had been made known by Hertz. Vertical antennæ connected with the ground had been previously used for sending and receiving by Dolbear in 1882 in connection with his system for telegraphing by electrostatic induction[b] and also later by Edison and others.

Hertz's receiver, the minute spark-gap, was not suited for wireless telegraphy, and before any telegraphic work could be done a suitable receiver had to be found.

The fact that tubes containing conducting powders had their resistance altered by the discharge of a Leyden jar and that the original resistance could be restored by tapping the tube was first noted by Munck. in 1835.[c]

In 1890 Branley showed that such a tube would respond to sparks produced at a distance from it.[d]

In 1892, at a meeting of the British Association at Edinburgh, Prof. George Forbes suggested that such a tube would respond to Hertzian waves.

In 1893 Professor Minchen demonstrated experimentally that such powders would respond to electro-magnetic waves generated at a distance.[e] He used a battery and galvanometer shunted around the powder to detect the effect of the waves.

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[a] For report of this work see Electrician, May 5, 1899.

[b] Dolbear, United States patent No. 350299, March 24, 1882.

[c] See Guthe "Coherer action," Transactions of the International Electrical Congress, St. Louis, 1904, p. 242. Munck., Poggendorff Ann., 1838, vol. 43, p. 193.

[d] Branley, Comptes Rendus, 1890, p. 785, and 1891, p. 90.

[e] Minchen, Proceedings Physical Society, London, 1893, p. 455.

Sir Oliver J. Lodge on June 1, 1894, delivered a lecture before the Royal Institution.[a] In this remarkable lecture Lodge described among other things the following:

1. The filings coherer.
2. The filings coherer in hydrogen under reduced pressure (this in a note added July, 1894).
3. The automatic tapper back for the coherer.
4. The metallic reflector for focusing the waves.
5. The connection of the coherer to a grounded conductor, i. e., a gas-pipe system.
6. The method of making the coherer so connected respond by setting up oscillations in a separate grounded system, i. e., a hot-water pipe system, in another part of the building.
7. The method of detecting distant thunderstorms by connecting the coherer to a grounded gas-pipe system.

In this lecture Professor Lodge stated that in his estimate the apparatus used would respond to signals at a distance of half a mile.

Early in 1895 Professor Popoff,[b] of Cronstadt, Russia, constructed a very sensitive filings coherer, one form of which was used in some surveying experiments by the Russian Government,[c] consisting of iron filings suspended by a magnet and resting upon a metallic plate or cup. Other forms consisted of filings in glass tubes with platinum electrodes. He used early in 1895 the automatic tapping back mechanism and substituted for the galvanometer an ordinary telegraphic relay. He operated this apparatus at a distance by means of a large Hertzian radiator. One terminal of his coherer was connected to a conductor fastened to a mast about 30 feet high on the top of the Institute building, and the other terminal of the coherer was grounded.

At the conclusion of his paper, which is dated December, 1895, Popoff made the following statement:

> In conclusion I can express the hope that my apparatus, with further improvements of same, may be adapted to the transmission of signals at a distance by the aid of quick electric vibrations as soon as the source of such vibrations possessing sufficient energy will be found.

Among other experimenters who were working on this subject at the same time may be mentioned Captain Jackson, of the British Navy, and Mr. A. C. Brown.

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[a] Sir O. J. Lodge, "The work of Hertz," Proceedings Royal Institution, June 1, 1904, vol. 14, p. 321.

[b] Journal Russian Physico-Chemical Society, vol. 27, April 25, 1895.

[c] A. S. Popoff, "Apparatus for detection and registration of electrical vibrations," Journal Russian Physico-Chemical Society, vol. 28, December, 1895.

Marconi, on June 2, 1896, filed a provisional specification [a] showing two forms of apparatus, one similar to Lodge's 1894 apparatus using ungrounded aerials for both sending and receiving and the other for use "when transmitting through the earth or water" substantially identical with Lodge's 1894 and Popoff's 1895 apparatus, with tapper back, etc., and the receiving antenna only being grounded.

Soon after, in July, 1896, Marconi arrived in England and made a number of experiments for the English post-office at Salisbury Plain and elsewhere, using ungrounded aerials and parabolic reflectors and succeeded in reaching nearly 2 miles.

On March 2, 1897, Marconi filed the complete specification in which was included a statement that the transmitting antenna also could be grounded.

Lodge filed a provisional specification [b] showing radiating spheres, but no antenna, on May 10, 1897. The complete specification filed on February 5, 1898, shows as one form both antennæ grounded and also the use of an inductance wound in the form of a coil for the purpose of diminishing the rate of damping of the waves.

So far as is known little work was done in America during this period. The writer made some experiments in 1896 and in conjunction with two of his students, Messrs. Bennett and Bradshaw, did considerable work on receivers of various types in the fall of 1896 and spring of 1897, the results of which were incorporated in a thesis.[c]

Return to First Principles and Foundation, on Lines Antithetical to Old, of New or Sustained Oscillation Nonmicrophonic Receiver Method (1898).

Up to the year 1898, as may be seen from the above, the development of wireless telegraphy had proceeded along a single line. In that year, however, an entirely new method of wireless telegraphy was developed, characterized by a return to first principles, the abandonment of the previously used methods and by the introduction of methods in almost every respect their exact antitheses.

While the coherer is of more or less interest theoretically it is not adapted for use for telegraphic purposes. Responding as it does to voltage rises above a certain limit, it does not discriminate between impulses of different characters, and is therefore peculiarly susceptible to interfering signals and atmospheric disturbances, and the operation of coherer systems can not be guaranteed during the sum-

[a] Marconi, Great Britain patent No. 12039, 1896.

[b] Lodge, Great Britain patent No. 11575, 1897.

[c] Western University of Pennsylvania, May, 1897.

mer months or in the Tropics. Roughly speaking, a coherer acts by starting an arc and making a short circuit on the line every time a signal is received, which short circuit persists until it is broken by a blow from an additional mechanism, and such a method of operation is obviously far from practical. In addition, it is practically impossible to obtain sharp tuning in a local circuit containing a coherer; its action is always more or less erratic, its electrostatic capacity variable, and it is insensitive.

At the sending end the energy which can be liberated by the discharge of an antenna is limited, and in the form used prior to 1897 the dampening is so great that there are only a few oscillations per spark.

Lodge,[a] by placing a coil of large inductance in the antenna, throttled down the amount of energy radiated per oscillation and so obtained with the same limited amount of energy derived from the charged antenna, an increase in the time of damping.

Braun[b] patented the method of using a local oscillatory circuit connected to an antenna, the local oscillatory circuit having a much longer period than the natural period of the antenna and of a different order of magnitude. Such a system, however, does not radiate energy appreciably, and produces a damped wave.

This dampening and the limited amount of energy obtainable by charging and discharging the antenna operates to prevent sharp tuning and working over long distances.

The coherer is well adapted for working with damped waves, but the coherer-damped wave method can never be developed into a practical telegraph system. It is a question whether the invention of the coherer has not been on the whole a misfortune as tending to lead the development of the art astray into impracticable and futile lines and thereby retarding the development of a really practical system.

The fact that no coherer-damped wave system could ever be developed into a practically operative telegraph system, and the fact that it was necessary to return to first principles and initiate a new line of development along engineering rather than laboratory lines was perceived in America in 1898[c] and a new method was advised which may be called the sustained oscillation-nonmicrophonic receiver method as opposed to the damped oscillation-coherer method previously used.

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[a] Lodge, Great Britain patent No. 11575, 1897.

[b] Braun, German patent No. 11578, October 14, 1898.

[c] Electrical World, July 29, August 12, September 16, 1899, and Proceedings American Institute of Electrical Engineers, November, 1899, page 635, and November 20, 1906, page 781.

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Fundamental Differences Between the Old and New Wireless Schools.

The differences between the two methods are shown in tabulated form:

	Damped oscillation-coherer method.	Sustained oscillation-nonmicrophonic method.
A 1	Damped oscillations are produced at the sending end.	Sustained oscillations are produced at the sending end.
A 2	The energy transmitted is obtained by charging the antenna and discharging it.	The energy transmitted is derived from a local source and fed into the antenna.
A 3	A spark gap is used for producing the oscillations.	An arc or high frequency dynamo is generally used for producing the oscillations.
B 1	Imperfect or microphonic contact receivers are used.	Nonmicrophonic contact receivers are used.
B 2	The action of the receiver depends upon the voltage rise and is independent of the amount of energy received.	The receiver response is determined by the integral amount of energy received.
B 3	An open-tuned circuit is used for receiving.	A closed tuned circuit is used for receiving.
B 4	The receiving circuit is tuned to the wave frequency only.	The receiving circuit may be tuned to a group frequency as well as to the wave frequency.
C 1	In transmitting messages the production of the electromagnetic waves is intermittent.	The waves are preferably generated continuously and the transmission accomplished by changing the character of the wave.
C 2	The wave energy flux is intermittent	The wave energy flux is constant.
C 3	A high voltage is used	A low voltage is used.
C 4	Comparatively short wave lengths are used.	Comparatively long wave lengths are used.
C 5	The signals consist of dots and dashes, whose interpretation is fixed.	The signals may consist of dots only, whose interpretation depends on the station sending and receiving.
D 1	Antennæ are used adapted, roughly speaking, to utilize the electrostatic component of the electromagnetic waves.	The antennæ are preferably arranged so as to utilize the other component of the electromagnetic waves instead of the electrostatic component.

The history of these two antithetical lines of development will be treated of separately.

Development and Perfecting of Sustained Oscillation-nonmicrophonic Receiver Method (Period 1898–1902).

The current-operated receiver.

The first essential for the development of the system was, of course, a quantitatively responsive receiver. Several forms of this were tried, including the modification of the Boys' radio-micrometer (consisting of a light thermo couple suspended in the field of a per-

manent magnet and heated by radiation from a wire, which in turn was heated by the current to be detected) described by the writer at the Columbus meeting of the American association in 1897.[a] This was abandoned in favor of Prof. Elihu Thomson's alternating-current galvanometer,[b] suitably modified for telegraphic work.[c]

Among other forms of current-operated receiver may be mentioned the following:

The hot-wire barretter,[d] consisting of a minute platinum wire a few hundred thousandths of an inch in diameter and approximately a hundredth of an inch in length. The term "barretter" was coined for this device for the reason that it differs essentially from the bolometer of Langley in that it is arranged to be affected by external sources of radiant heat as little as possible instead of as much as possible, and to have an extremely small specific heat, an object not sought in the case of the bolometer.

The liquid barretter,[e] in which the change of resistance is effected by heating a liquid, the concentration of path being obtained by means of a fine platinum wire point. Some question has been raised as to the theory of operation of this device, but I think there is no question but that the effect is due to heat, though what per cent of the effect is due to change in ohmic conductivity by heat and what per cent is due to depolarization by heat is still, as originally stated by the writer,[e] uncertain. The facts that the device operates practically equally well irrespective of which terminal is connected to the local battery, and that the effect varies as the square of the alternating current (as a heat-operated device should do) instead of directly with the alternating current as a rectifier would do, and that depolarization is produced by the heat, have been confirmed by Dr. L. W. Austin.[f] The writer has experimentally determined the fact that though the electrical impulses may have a duration of less than a millionth part of a second, the change in resistance persists for approximately the ten thousandth part of a second, which would seem to show conclusively that the action is not a direct effect of the waves.

The term electrolytic receiver has sometimes been applied to the liquid barretter. This is objectionable, as there are a number of electrolytic receivers. For example, the Neughschwender-Schaefer[g]

[a] Electrician, June 24, 1904.

[b] Elihu Thomson, United States patent No. 363185, January 26, 1887.

[c] United States patents Nos. 706736 and 706737, December 15, 1899.

[d] United States patent No. 706744, June 6, 1902.

[e] United States patent No. 727331, April 9, 1903.

[f] Austin, Bulletin of the Bureau of Standards, vol. 2, No. 2.

[g] Neughschwender, German patent No. 107843, December 13, 1898, and Schaefer, British patent No. 6002, 1899.

receiver, in which a number of microscopic filaments are produced between two terminals by electrolysis, which filaments are ruptured by the wave-produced oscillations, thus increasing the resistance; also the liquid coherer of Captain Ferrie, described by him as follows:[a]

> The same effect of self-decohering coherence has been determined for a contact of a metallic wire and a liquid conductor, acidulated water, contained in a glass tube of small diameter, and placed under the same conditions as the preceding. Always, the sensitiveness of this contact is very notably inferior to that obtained in the experiments disclosed above. The maximum sensitiveness was obtained when the resistance of the imperfect contact was about 2,000 ohms and when the extremity of the metal wire scarcely grazed the meniscus of the liquid. The results obtained were better with a copper wire, attacked by the acidulated water, than with a platinum wire.

This coherer probably acts through a chemical effect producing a thin film of gas and has never come into use, doubtless because, as Captain Ferrie points out, it is even less sensitive than the Marconi coherer. Also the rectifier of Pupin,[b] in which the terminals are placed so closely together that practically no energy is absorbed in the receiver, in order that the rectified energy may be utilized outside in the external circuit, in opposition to the liquid barretter, where the position of the terminals is such that all the received wave energy is absorbed in the barretter for the purpose of producing a secondary effect, and so influencing the current in a shunted local circuit.

METHODS OF OBTAINING SUSTAINED OSCILLATIONS.

Spark-gap, and local oscillatory or "tank" circuit.—Prof. Elihu Thomson discovered that by using a transformer without an iron core (the well-known Elihu Thomson air-core transformer, later used by Tesla and others) and a spark-gap and condenser in the primary circuit, and with the secondary circuit suitably tuned great resonant rises of potential could be obtained. In 1892 he constructed such a transformer giving discharges 64 inches long.[c]

The same method was later used by Tesla[d] in his experimental researches and in his attempt to carry out Loomis's[e] method of transmitting a current through a hypothetical conducting stratum in the upper regions of the atmosphere.

The device, suitably modified for wireless telegraphic purposes, so as to give, instead of a continuously cumulative rise of potential, an initial rise of potential followed by a gradual feeding in of the energy from the local circuit to supply the energy lost from radiation,

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[a] Blondel, L'Eclairage Electrique, September 29, 1900.

[b] Pupin, United States patent No. 713044, January 4, 1898.

[c] Electrical World, February 20 and 27, 1892.

[d] United States patent No. 645516, September 2, 1897.

[e] Loomis, United States patent No. 129971, July 30, 1872.

was made use of in 1898 for the purpose of producing prolonged trains of sustained waves.

Various types of connection between the antenna and the local oscillatory circuit were tested, but it was found that the most efficient results were obtained by connecting the local circuit directly across the spark-gap.[a]

The results of some comparative tests are here given. The figures in the column "A" are for the local circuit connected directly to the terminals of the spark-gap, those in column "B" are for an auto-transformer, those in column "C" for a loose-coupled primary and secondary.

	A.	B.	C.
Frequency	212,000	212,000	212,000
Tank capacity (m. f.)	0.072	0.072	0.072
Kilowatt output dynamo	30	30	30
Tank current (amperes)	400	370	300
Antenna current	48.5	46	48

The large station at Brant Rock is operated with the local circuit directly connected across the spark-gap, partly because the efficiency is somewhat greater, but also on account of the great simplification of connections and the fact that the degree of sustainment of the wave train may be adjusted very simply, if desired, by sliding the lower terminal of the antenna along a few inches of the lead of the local oscillatory circuit.

Cooper-Hewitt[b] in 1902 used a modification of his mercury lamp to obtain intermittent discharges, each followed by a train of high-frequency oscillations.

Arc methods.—The worker with high-frequency oscillatory currents will soon discover that we are indebted to the genius of Prof. Elihu Thomson for practically every device of any importance in this art.

The method of producing high frequency oscillations from an arc and continuous current was discovered by him in 1892.[c] Figure 1, taken from his patent, shows the general form of his arrangement. If the directions given in the specification are followed no difficulty will be met with in obtaining frequencies as high as 50,000 per second.

Between 1900 and 1902 some experiments were carried out with the Elihu Thomson arc as a source of high frequency oscillations for wireless telegraphy and telephony.

[a] United States patents Nos. 706735 and 706736, December 15, 1899.

[b] Cooper-Hewitt, United States patent No. 780999, April 25, 1902.

[c] Elihu Thomson, United States patent No. 500630, July 18, 1892.

Some difficulties were found, for example, the arc could not be started and stopped as quickly as was necessary for telegraphic purposes, and the intensity of the oscillations and their frequency varied considerably. These were overcome by making some minor improvements, for example, the difficulty in sending was overcome by permitting the arc to run continuously and using the key to change the electrical constants of the circuits.[a] The difficulty in keeping the intensity and frequency constant was overcome by substituting resistance for a portion of the inductance, and also by using the arc under pressure.[b]

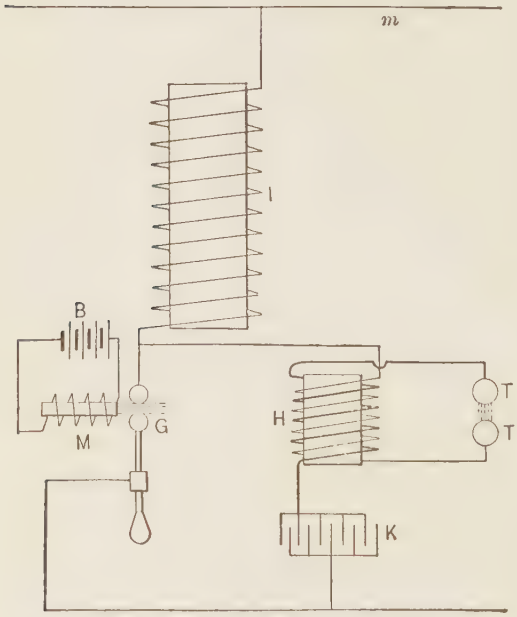

FIG. 1.—Elihu Thomson's method of producing high frequency oscillations.

Tests made by Doctor Austin[c] show that with this method frequencies as high as 3,000,000 per second and efficiencies as high as 60 per cent can be obtained together with an absolutely steady[d] generation of the high frequency currents and an absence of harmonic frequencies.

High frequency alternator.—The first high frequency alternator was built by Prof. Elihu Thomson in 1889. And it[e] was while experimenting with it in 1900 that Doctor Tatum made his very interesting discovery that high frequency currents of large amperage could be passed through the body without injury.[f]

[a] United States patents Nos. 706742, July 6, 1902; 706747, September 28, 1901; 727330, March 21, 1903; 730753, April 9, 1903.

[b] Ibid and United States patent No. 706741.

[c] Austin, Bulletin of the Bureau of Standards, vol. 3, No. 2.

[d] Austin assumed from the figure he obtained for the dampening, that the oscillations were not continuous; but the method used for determining the dampening is not applicable to this case, and a comparison of the currents and voltages with the frequencies given in Austin's experiments, shows that these oscillations must have been continuous.

[e] Thomson, Electrical Engineer, July 30, 1890, and London Electrician, September 12, 1890.

[f] Thomson, Electrical Engineer, March 11, 1891.

From 1898 to 1900 numerous experiments were made on antennæ of large capacity, and it was found that instead of using sheets of solid metal or wire netting, single wires could be placed at a considerable fraction of the wave-length apart and yet give practically the same capacity effect as if the space between them were filled with solid conductors.

From other investigations on the variation of radiation with frequency the result was arrived at that it should be possible to construct an alternating-current dynamo of sufficiently high frequency and output to give ample radiation for wireless telegraphic purposes.[a]

In 1900 a large American electrical manufacturing company kindly consented to take up the construction of such a dynamo. As a preliminary, a dynamo of 1 kilowatt output and 10,000 cycles (shown in pl. 1, fig. 1) was built in 1902. By the summer of 1906 many of the difficulties had been overcome, and a machine giving 50,000 cycles was installed at the Brant Rock station. Various improvements were made by the writer's assistants, and in the fall of 1906 the dynamo was working regularly at 75,000 cycles, with an output of half a kilowatt, and was being used for telephoning to Plymouth, a distance of approximately 11 miles. In the following year machines were constructed having a frequency of 100,000 cycles per second and outputs of 1 and 2 kilowatts.

The credit for the development of this machine is due to Messrs. Steinmetz, Haskins, Alexanderson, Dempster, and Geisenhoner, and also to the writer's assistants, Messrs. Stein and Mansbendel.

CLOSED TUNED CIRCUITS.

In 1898 the open tuned circuits originally used were discarded for closed tuned circuits,[b] and it was discovered that valuable selective effects could be obtained by placing the condenser in shunt to the inductance, instead of in series with it.[b]

COMBINATION OF WAVE AND GROUP TUNING.

The fact that if selectivity is obtained solely by tuning to wave frequencies, the number of stations is limited, was appreciated at an early date. In 1900[c] a new method was developed, the stations being tuned both to the wave frequency and to an independent or group frequency, so that stations might obtain selectivity by varying either the wave or the group frequency and thus have at their disposal a

[a] United States patent No. 706737, May 29, 1901.

[b] United States patents Nos. 706735 and 706736, December 15, 1899.

[c] United States patents Nos. 727325, June 2, 1900, and 727330, March 21, 1903.

virtually unlimited number of combinations and be practically free from atmospheric disturbances. Plate 1, fig. 2, shows a type of group tuner.

FURTHER DEVELOPMENT OF DAMPED WAVE-COHERER METHOD.

Marconi, by 1898, had carried the development of the filings coherer to its maximum point.

Lodge in 1897[a] had disclosed the open secondary circuit for receiving.

Marconi in 1898[b] greatly improved this by adjusting the length of the secondary so as to tune it, and by the aid of this improvement was enabled to telegraph a distance of 35 miles[c] in October, 1899.

Lodge in 1902[d] invented what is perhaps the most perfect form of coherer, consisting of a thin steel disk dipping in oil-covered mercury and automatically decohered by being kept in continuous rotation.

A number of self-restoring coherers, of which the Brown[e] carbon coherer may be taken as a type, including the mercury carbon coherer of Solari, came into more or less extended use, and also modifications of the imperfect contact receiver of Neugschwender.[f]

The small progress made along these lines is to be explained by the fact that the damped wave-coherer system is essentially and fundamentally incapable of development into a practical system.

Later Developments (Period 1902–1908).

Progress in Europe since 1902 has been marked by the gradual abandonment of the elements of the damped wave-coherer system and the substitution of elements of the sustained wave nonmicrophonic contact type.

In 1900[g] Marconi substituted for the plain aerial an aerial with the writer's tuned local circuit or tank circuit for sending, thus obtaining a considerable increase in range of transmission.

In 1902 Marconi invented a very ingenious form of current-operated receiver, called the magnetic detector,[h] and with this combination achieved some very remarkable results.

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[a] Lodge, Great Britain patent No. 11575, May 10, 1897.

[b] Marconi, Great Britain patent No. 12326, June 1, 1898.

[c] Official report United States Navy of test U. S. S. *Massachusetts*, October, 1899.

[d] Lodge, Muirhead & Robinson, Great Britain patent No. 13521, June 14, 1902.

[e] Brown & Neilson, Great Britain patent No. 28955, December 17, 1896.

[f] A. Neugschwender, Wied. Ann. der Physik, 1899, vol. 67, p. 430. Schaefer, British patent No. 6002, 1899.

[g] Marconi, Great Britain patent No. 7777, April 26, 1900.

[h] Marconi, Great Britain patent No. 10245, 1902.

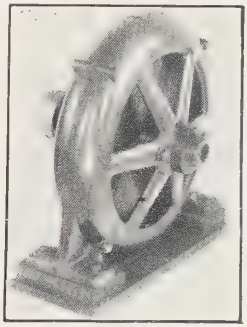

FIG. 1.—PRELIMINARY DYNAMO, 1 KILOWATT, 10,000 CYCLES.

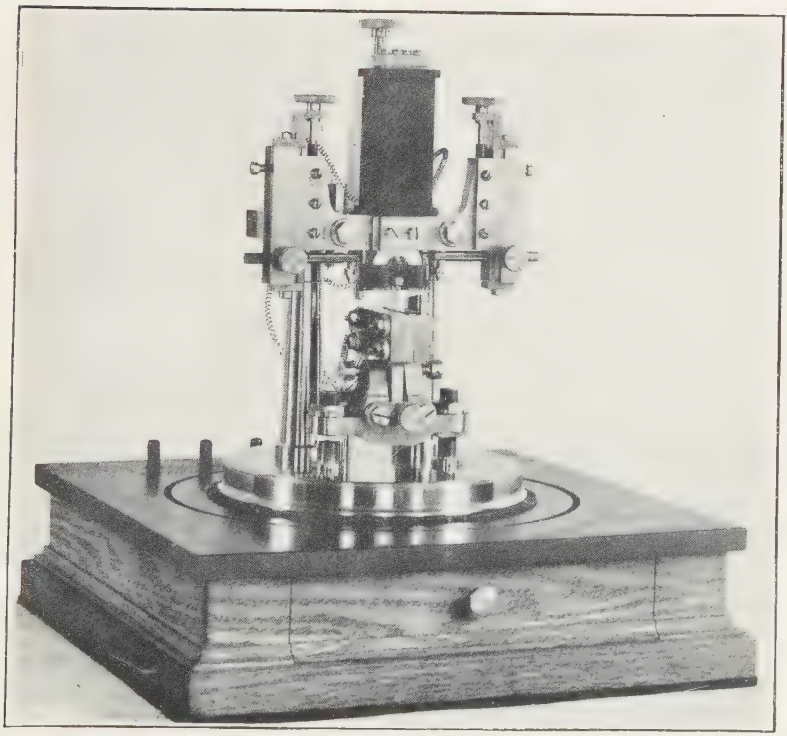

FIG. 2.—TYPE OF GROUP TUNER.

In 1905 Professor Fleming [a] invented a very efficient detector based on the "Edison effect" in incandescent lamps, and the observations of Elster and Geitel [b] on the rectifying effect of such an arrangement on Hertzian oscillations.

Virtually nothing was done in Europe in the way of producing sustained oscillations by the arc or high frequency method until recently, possibly because of Duddell's erroneous statement [c] to the effect that frequencies much above 10,000 could not be obtained by the Elihu Thomson arc method, and Fleming's statement [d] that an abrupt impulse was necessary and that high frequency currents, even if of sufficient frequency, could not produce radiation.

In 1903 Poulsen [e] invented an interesting modification of the Elihu Thomson arc, which consists in forming the arc in hydrogen instead of in air or compressed gas as previously done. This modification is not, however, so efficient as the older methods and gives oscillations varying in amplitude and intensity and accompanied by strong harmonics,[f] but I have considered it worth mentioning on account of the amount of interest it appears to have excited in Europe.

Some very important and interesting papers on electrical oscillations were published during these years by Oberbeck,[g] Wien,[h] Drude,[i] and Bjerknes.[j]

In America the development of the sustained oscillation nonmicrophonic system has proceeded steadily and it may now be said to have reached the stage of commercial practicability. On account of the amount of work which has been done it is impossible to refer to more than a few of the recent advances.

The following are some of the later types of detectors:

The frictional receiver,[k] in which the waves produce a change of friction between two moving surfaces and so cause an indication.

The heterodyne receiver,[l] in which a local field of force actuated by a continuous source of high-frequency oscillations interacts with a field produced by the received oscillations and creates beats of an audible frequency.

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[a] Fleming, Proceedings Royal Society London, 1905, vol. 74.

[b] Elster and Geitel, Wied. Ann. de Physik, vol. 52, p. 433.

[c] Duddell, The Electrician, 1903, vol. LI, p. 902.

[d] Fleming, Proceedings of the International Congress, St. Louis, 1904, vol. 3, p. 603.

[e] Poulsen, United States patent No. 789449, June 19, 1903.

[f] Austin, Bulletin of the Bureau of Standards, vol. 3, No. 2.

[g] Oberbeck, Wied. Ann. der Physik, vol. 55, 1895.

[h] Wied. Ann. der Physik, vol. 8, 1902.

[i] Drude, Ann. der Physik, vol. 13, 1904.

[j] Bjerknes, Ann. der Physik, vol. 44, 1891, and vol. 47, 1892.

[k] United States application No. 251538, March 22, 1905.

[l] United States application No. 271539, June 28, 1905.

The so-called "thermoelectric receivers" of Austin,[a] Pickard,[b] and Dunwoody.[c]

The "audion" of De Forest,[d] a very interesting and sensitive device, which though superficially resembling Professor Fleming's rectifier appears to act on an entirely different principle.

The Cooper-Hewitt mercury receiver, about which little is known, but which appears to be very sensitive.

The following are some of the later methods of producing sustained oscillations:

The substitution of a number of arcs in series having terminals of large heat capacity in place of the single arc in the arc method.[e]

The use of regulating or "fly-wheel" circuits in connection with the arc method.[e]

The method of producing oscillations shown in plate 2, figure 1, by using two arcs and throwing the discharge from one side to the other alternately at a frequency regulated by the constants of the electric circuit.[e]

The condenser dynamo[f] which consists of two radially slotted disks separated by a mica diaphragm, charged by a continuous current source of potential, and rotating in opposite directions.

Two-phase high-frequency dynamo method.[g]

Commutator method.[h] In this method the high frequency is produced by means of a ball rotating at high speed on the interior surface of a commutator (pl. 2, fig. 2).

The helium arc method,[i] in which the arc is produced in helium or argon or similar gases.

The critical pressure method,[j] in which the electrodes extend within a certain critical distance, depending upon the pressure used, so that the discharge always passes at the same voltage irrespective of the distance between the electrodes.

Methods of signaling.—Continuous production of waves but changing constants of sending circuit.[k]

The inverted method of sending and the method of signaling by sending dots, the interpretation of which is determined by similar commutators at the sending and receiving stations.

---

[a] Austin, United States application No. 319241, May 29, 1906.

[b] Pickard, United States application No. 342465, November 8, 1906.

[c] Dunwoody, United States patent No. 837616, March 23, 1906.

[d] De Forest, United States patent No. 836070, January 18, 1906.

[e] United States application No. 291737, December 14, 1905.

[f] United States application No. 291739, December 14, 1905.

[g] United States patent No. 793649, March 30, 1905.

[h] United States application No. 316521, May 12, 1906.

[i] United States application No. 351560, January 7, 1907.

[j] United States application No. 355787, February 4, 1907.

[k] United States patents Nos. 706747, September 28, 1901; 706742, June 6, 1902; 727747, March 21, 1903.

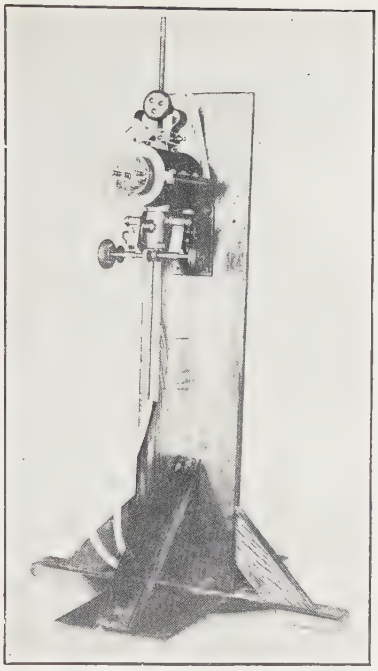


FIG. 1.—APPARATUS FOR PRODUCING OSCILLATIONS.

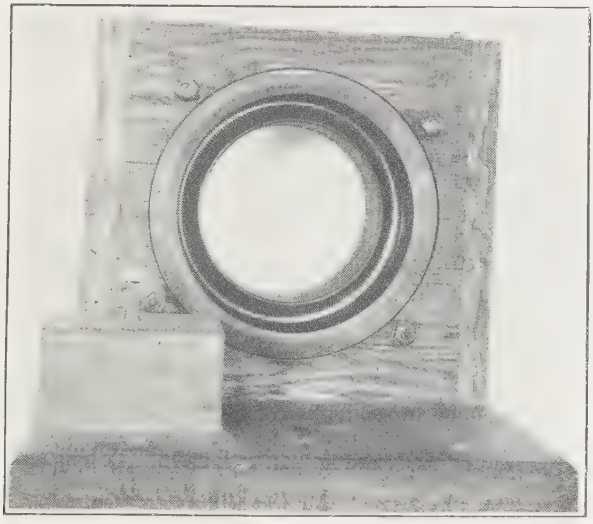


FIG. 2.—COMMUTATOR METHOD OF PRODUCING OSCILLATIONS.

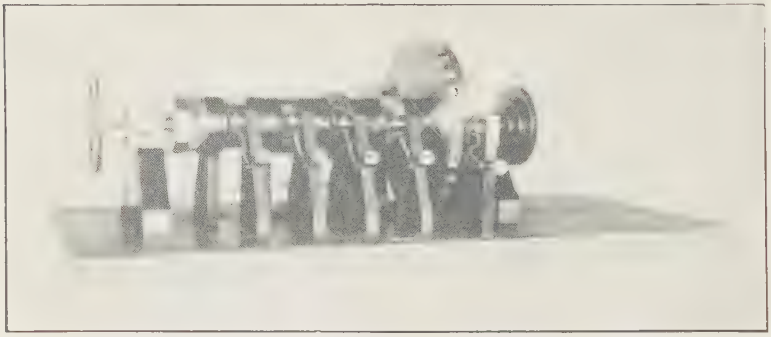


FIG. 1.—HARMONIC INTERRUPTER FOR DETERMINING VARIATION OF INTENSITY WITH CHANGE OF NOTE.

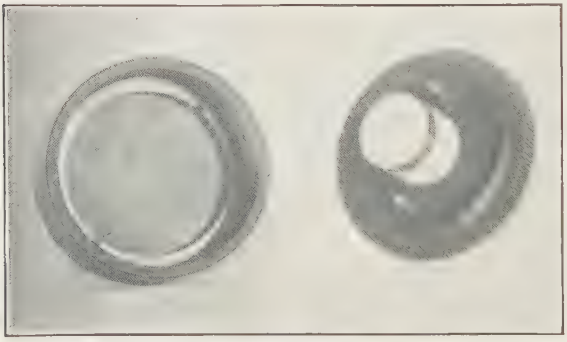


FIG. 2.—WIRELESS TELEPHONE RECEIVER, WITH THIN COPPER DIAPHRAGM REPELLED BY RESISTANCE COIL OF 16 OHMS.

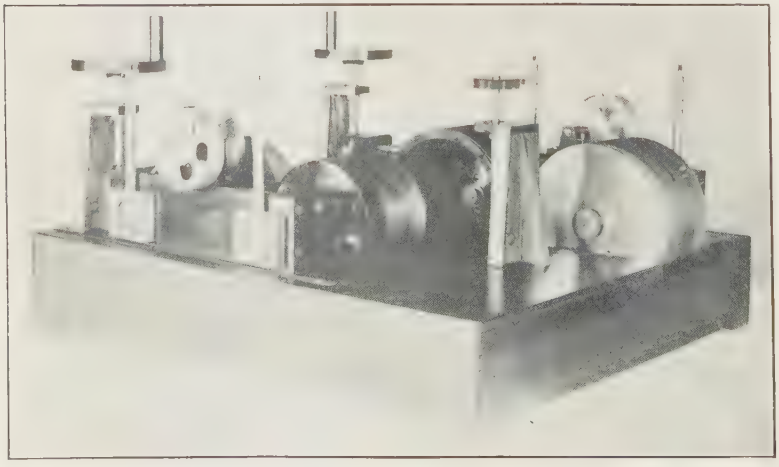


FIG. 3.—TRANSFORMER USED IN TRANSMITTING CIRCUIT.

Duplex and multiplex methods.—A considerable number of these have been worked out, mostly operating either by balance methods[a] or commutators.[b] It is impossible to discuss all the various improvements, such, for example, as the method of indicating the busy and free state of a station, the methods of sending and receiving in one direction, the various types of aerials used for receiving the other components of the electromagnetic waves besides the electrostatic component, etc.

Plate 3, figure 1, shows the harmonic interrupter for determining the variation of intensity with change of note.

Plate 3, figure 2, shows a type of receiver described in United States patent No. 706747, in which the telephone diaphragm is formed of thin copper and repelled by a fixed coil having a resistance of about 16 ohms. The principle of this receiver was discovered by Prof. Elihu Thomson. It has been used for wireless telephony for a distance of 11 miles with fairly satisfactory results.

Plate 3, figure 3, shows a transformer used in the transmitting circuit. The number of primary and secondary turns can be altered continuously, and also the degree of coupling. The wire is wound off from an insulating cylinder onto a cylinder of copper, and the cylinder of copper, forming a closed circuit secondary of the transformer, annuls the inductance of that portion of the wire wound upon the copper cylinder.

Plate 4 shows a group-tuned call; that is, a vibration galvanometer which operates a selenium cell and rings a bell when a call is received.

Plate 5, figure 1, shows an apparatus for determining the best shape of coil for use with the heterodyne receiver.

THEORY OF WIRELESS TELEPHONY.

For wireless telephony three things are necessary:

1. Means for radiating a stream of electrical waves sufficiently continuous to transmit the upper harmonics on which the quality of the talking depends.

2. Means for modulating this stream of waves in accordance with the sound waves.

3. A continuously responsive receiver, giving indications proportional to the energy received and capable of responding with sufficient rapidity to the speech harmonics.

Work on the wireless telephone was commenced before a satisfactory means was discovered for producing sustained oscillations.

To ascertain the number of sparks per second which was necessary to determine articulate speech, a phonograph cylinder was taken

[a] United States application No. 366528, April 5, 1907.

[b] United States patent No. 793652, April 6, 1905.

and grooves were cut in it longitudinally. It was found in this way that practical transmission could be accomplished with 10,000 breaks per second. It is believed now that this number is unnecessarily high, possibly owing to the fact that it was impossible to cut the grooves on the cylinder without producing ridges. The lower limit may be fixed in another way.

Electrical circuits met with in actual working have resistance, self-inductance capacity, and leakance. Heaviside gave the differential equations for the pressure and current over such circuits when alternating voltages were applied, but no method of solution being known, the mathematical treatment of such circuits was restricted to cases where one of the constants was neglected, until Dr. A. E. Kennelly in a masterly series of papers gave the complete solution.

The results were immediately found applicable to a great variety of problems, such as the transmission of signals through cables and of telephonic speech through various types of circuits.

In this way Doctor Kennelly[a] by comparing the results obtained by Dr. Hammond V. Hayes[b] in practical telephonic transmission over loaded lines with the theoretical values of the current for different harmonics showed that harmonics above 2,000 per second could be neglected for telephonic transmission.

The writer has never succeeded in obtaining good talking with such a low frequency, but under favorable conditions fairly satisfactory speech may be obtained with 5,000 interruptions per second. For really good transmission, however, the radiation must be practically continuous, for if the spark frequency is less than 20,000 per second there is a disagreeable high pitch note in the telephone, not noticeable perhaps at first but apt to become annoying with use. The most satisfactory way is, of course, to use a source of sustained oscillations.

It fortunately happens that for wireless telephonic purposes it is inadvisable to use a wave frequency of less than 25,000 per second, on account of the difficulty in radiating energy with low frequencies.

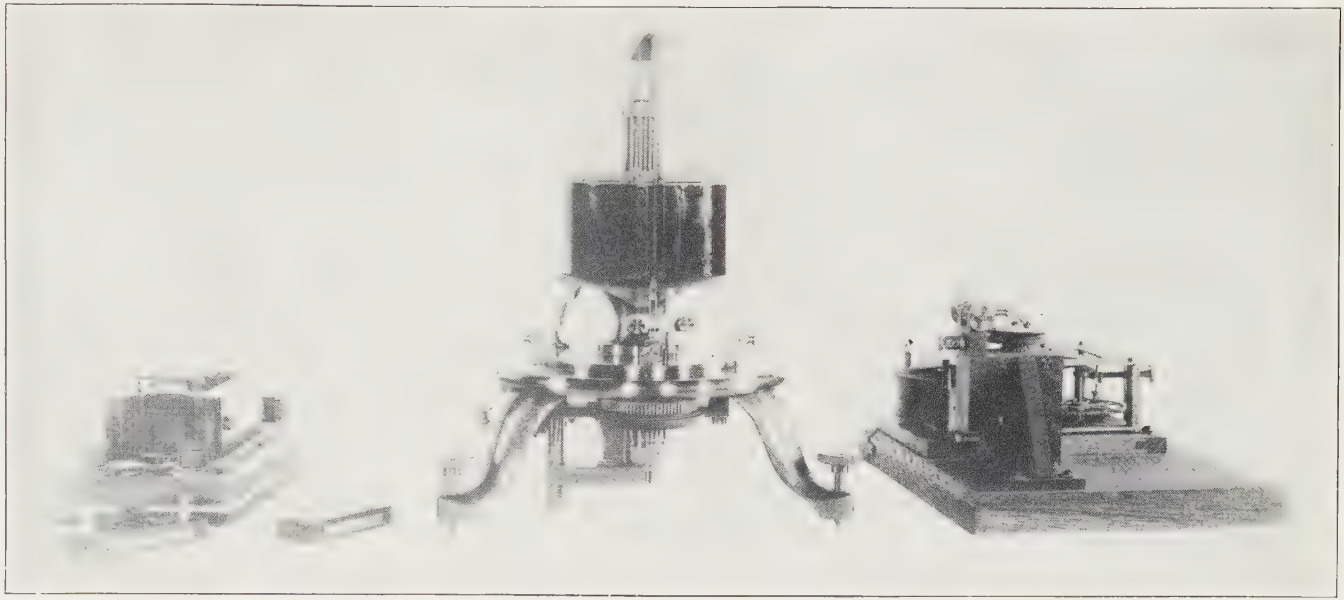
The receiver must, of course, be continuously responsive. If, for example, it had to be tapped back in order to restore it to the responsive condition, speech could not be transmitted.

It must also give indications proportional to the energy received or the character of the speech will be distorted.

It must also respond with sufficient rapidity. If, for example, it takes a thousandth of a second to restore itself to its original resist-

[a] Kennelly, "Distribution of pressure and current over alternating-current circuits," Harvard Engineering Journal, 1906, p. 43.

[b] Hayes, "Loaded telephone lines in practice," Transactions International Electrical Congress, St. Louis, vol. 3.



A GROUP-TUNED CALL; VIBRATION GALVANOMETER OPERATING A SELENIUM CELL, WHICH RINGS A BELL WHEN CALL IS RECEIVED.

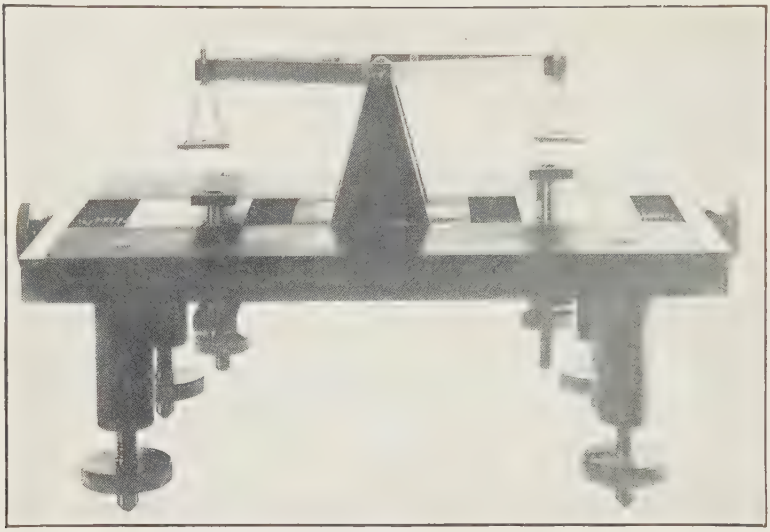


FIG. 1.—APPARATUS FOR DETERMINING BEST SHAPE OF COIL FOR USE WITH THE HETERODYNE RECEIVER.

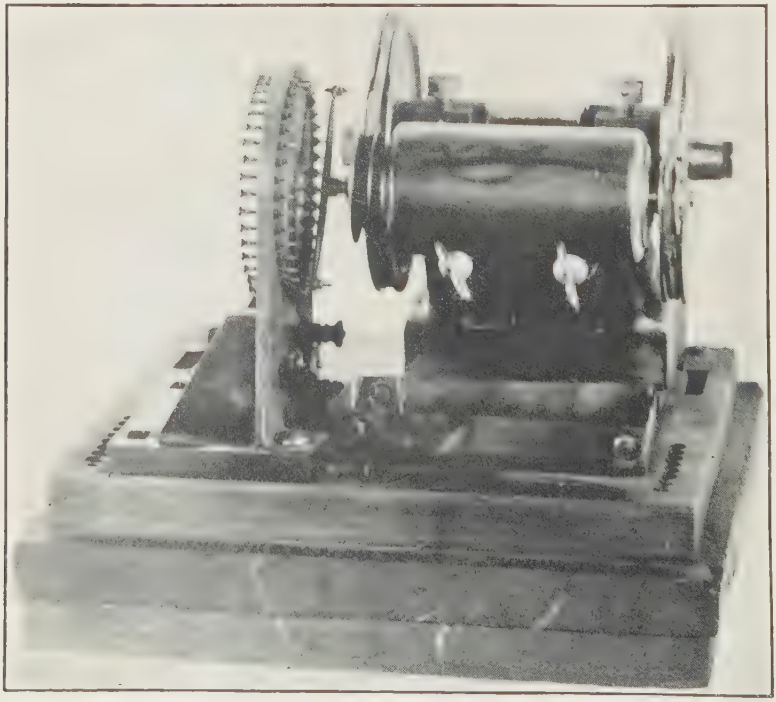


FIG. 2.—ROTATING SPARK GAP GIVING APPROXIMATELY 20,000 DISCHARGES PER SECOND.

ance the receiver will obviously not record the higher harmonics. I have experimentally determined that a receiver which restores itself in the ten thousandth part of a second acts with sufficient rapidity.

HISTORY OF THE DEVELOPMENT OF WIRELESS TELEPHONY.

The writer has been asked on several occasions how the wireless telephone came to be invented. In November, 1899, shortly prior to the delivery of my previous paper,[a] while experimenting with the receiver shown in figure 3 of that paper, I made some experiments with a Wehnelt interrupter for operating the induction coil used for sending.

In the receiver mentioned the ring of a short-period Elihu Thomson oscillating current galvanometer rests on three supports, i. e., two pivots and a carbon block, and a telephone receiver is in circuit with the carbon block. A storage battery being used in the receiver circuit[b] it was noticed that when the sending key was kept down at the sending station for a long dash the peculiar wailing sound of the Wehnelt interrupter was reproduced with absolute fidelity in the receiving telephone. It at once suggested itself that by using a source with a frequency above audibility wireless telephony could be accomplished.

Professor Kintner, who was at that time assisting me in these experiments and to whose aid their success is very largely due, was kind enough to make the drawings for an interrupter to give 10,000 breaks per second. Mr. Brashear, the celebrated optician, kindly consented to make up the apparatus, and it was completed in January or February, 1900.

The experimental work was, however, delayed, as the writer was at that time transferring his laboratory from Allegheny, Pennsylvania, to Rock Point, Maryland, and it was not until six months later that the stations at that point were completed and a suitable mast was erected for trying the apparatus.

The first experiments were made in the fall of 1900 with the above-mentioned apparatus, which was supposed to give 10,000 sparks per second, but which probably gave less. Transmission over a distance of 1 mile was attained, but the character of the speech was not good and it was accompanied by an extremely loud and disagreeable noise, due to the irregularity of the spark.

By the end of 1903 fairly satisfactory speech had been obtained by the arc method above referred to, but it was still accompanied by a disagreeable hissing noise. In 1904 and 1905 both the arc method and

[a] Transactions American Institute Electrical Engineers, November 22, 1899.

[b] United States patent No. 706736, December 15, 1899.

another method in which the 10,000 cycle alternator above referred to was employed had been developed to such an extent that the apparatus could be used practically and sets were advertised and tendered to the United States Government.[a] The transmission was, however, still not absolutely perfect.

By the fall of 1906 the high frequency alternator had been brought to a practical shape and was used for telephoning from Brant Rock to Plymouth, a distance of 11 miles, and to a small fishing schooner, this being the first instance in which wireless telephony was put in practical use. The transmission was perfect and was admitted by telephone experts to be more distinct than that over wire lines, the sound of breathing and the slightest inflections of the voice being reproduced with the utmost fidelity.

As it was realized that the use of the wireless telephone would be seriously curtailed unless it could be operated in conjunction with wire lines, telephone relays were invented both for the receiving and transmitting ends, and were found to operate satisfactorily, speech being transmitted over a wire line to the station at Brant Rock, retransmitted there wirelessly by a telephone relay, received wirelessly at Plymouth, and there relayed out again on another wire line. On December 11, 1906, invitations were issued to a number of scientific men to witness the operation of the wireless transmission in conjunction with the wire lines. A report of these tests appeared in the American Telephone Journal of January 26 and February 2, 1907, the editor being one of the men present.

In July, 1907, the range was considerably extended and speech was successfully transmitted between Brant Rock and Jamaica, Long Island, a distance of nearly 200 miles, in daylight and mostly over land,[b] the mast at Jamaica being approximately 180 feet high.

In 1907 several European experimenters succeeded in transmitting speech wirelessly, using some of the earlier forms of the writer's arc method, and some months ago the vessels of our Pacific squadron were equipped with wireless telephones, using this arc method, by another American company.

METHODS AND APPARATUS.

Methods and Apparatus for Producing the Electromagnetic Waves.

These have been already referred to. Plate 5, figure 2, shows a rotating spark gap giving approximately 20,000 discharges per second. This was connected to a 5,000-volt source of direct current.

[a] Letter of July 8, 1905; see The Electrician, London, February 22, 1907; also catalogue of 1904 and subsequent.

[b] "Long distance wireless telephony," The Electrician, October 4, 1907.

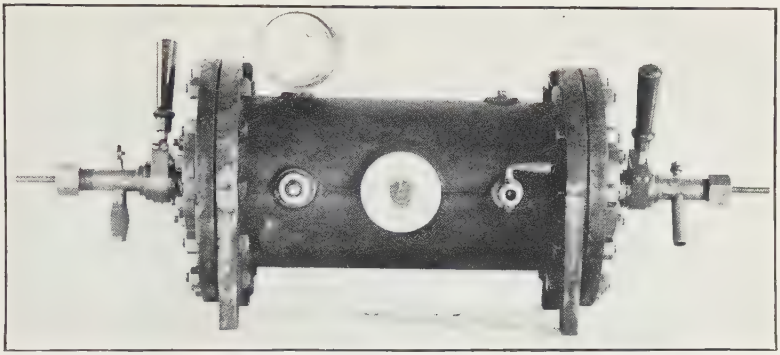


FIG. 1.—APPARATUS FOR OPERATING ELECTRIC ARC IN GAS UNDER PRESSURE AND IN VACUUM, AND THE CRITICAL DISTANCE ARC.

FIG. 2.—APPARATUS FOR OPERATING ELECTRIC ARC IN GAS UNDER PRESSURE.

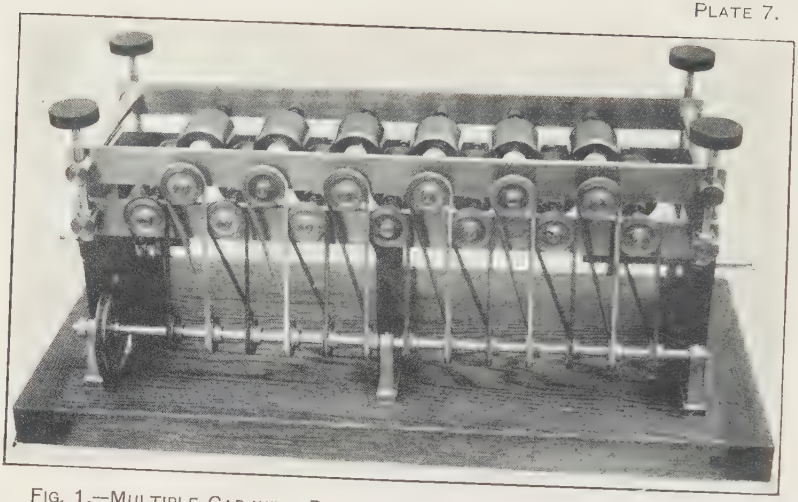


FIG. 1.—MULTIPLE GAP WITH ROTATING ELECTRODES; BRASS, AMALGAMATED ZINC, AND GRAPHITE USED.

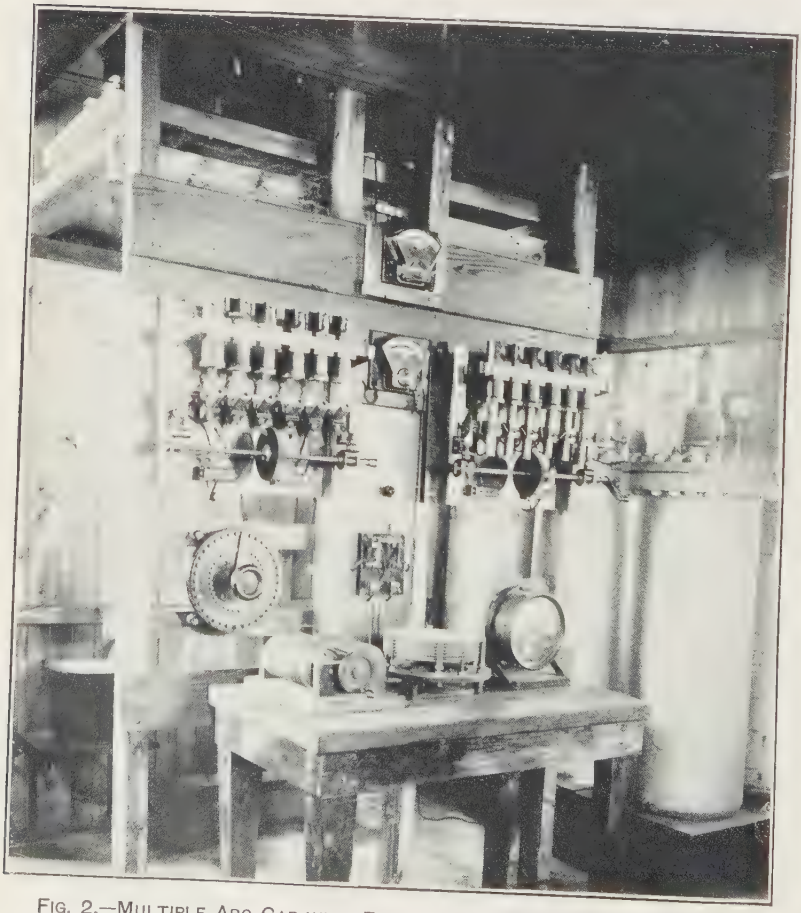


FIG. 2.—MULTIPLE ARC GAP WITH ELECTRODES OF DIFFERENT MATERIALS; UPPER TERMINALS WATER COOLED.

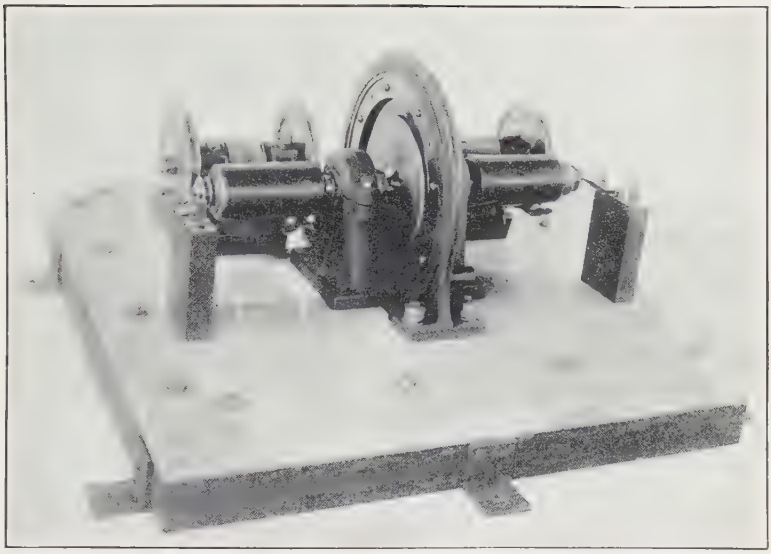


FIG. 1.—CONDENSER DYNAMO.

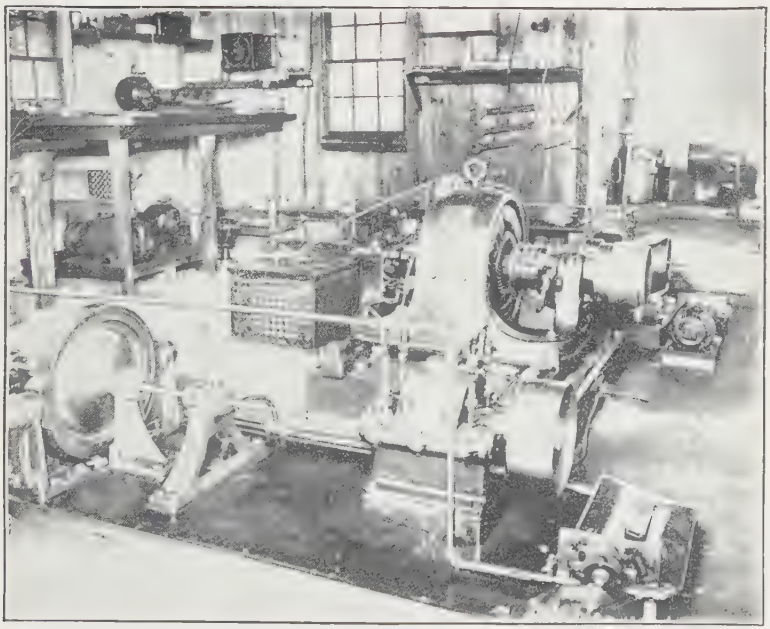


FIG. 2.—TYPE OF HIGH-FREQUENCY ALTERNATOR.

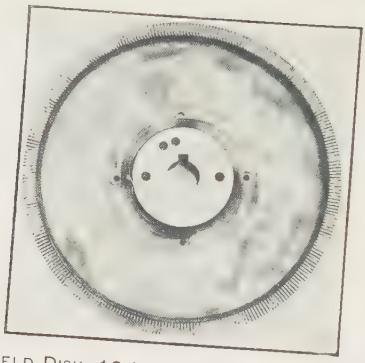


FIG. 1.—FIELD DISK, 12 INCHES IN DIAMETER, 300 SLOTS.

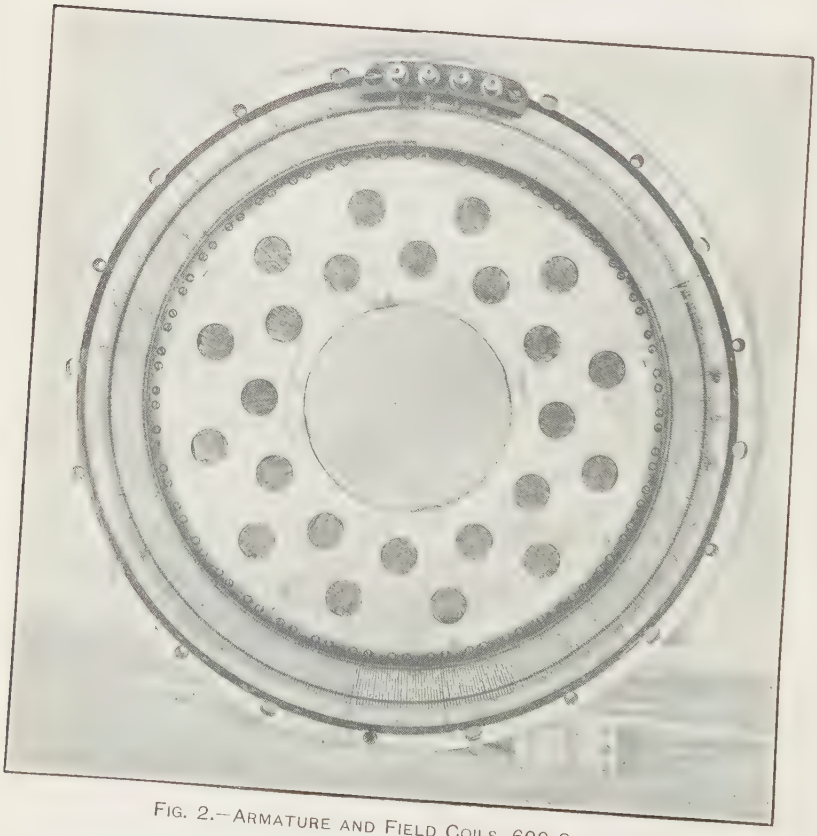


FIG. 2.—ARMATURE AND FIELD COILS, 600 SLOTS.

The terminals are of 40 per cent platinum-iridium. In operation the apparatus is arranged to charge a condenser to a definite potential and discharge it.

Plate 6 shows forms of apparatus for operating the arc in a gas under pressure.

The apparatus of figure 1 on plate 6 is also used for the arc in vacuum and the critical distance arc.

Plate 7, figure 1, shows a multiple gap with rotating electrodes, brass, amalgamated zinc, and graphite being used.

Plate 7, figure 2, shows a multiple arc gap with electrodes of different materials, the upper terminals being water cooled.

Plate 8, figure 1, shows a condenser dynamo.

Plate 8, figure 2, shows a general view of one type of high-frequency alternator. It is driven by a motor and a De Laval gear. It has been operated at 96,000 cycles per second, but is generally run at 81,700.

Plate 9, figure 1, shows a field disk; it is 12 inches in diameter and there are 300 slots on it.

Plate 9, figure 2, shows the armature and field coils. There are 600 armature slots, each containing two turns of 13 mil wire. The field current is 5 amperes. The resistance of the armature is 6 ohms; it gives 160 volts and about 7 or 8 amperes. Other armatures have been constructed having a resistance of 4 ohms. For some work double armatures are used giving about 270 volts. The output of the single-armature machines at 81,700 cycles is approximately 1 kilowatt. The output of the double-armature machine is approximately 2 kilowatts.

Other types of high-frequency alternators are under construction. One type shown in plate 10, figure 1, is designed for use on shipboard. The armature disk is 6 inches in diameter and two armatures are used. It is arranged to be mounted on gimbals and to be driven by a steam turbine connected to the steam pipe by flexible, armored steam hose. The frequency is about 100,000 and the output about 3 kilowatts.

Another type, which is at present being constructed by Mr. Alexanderson, to whose efforts the success of this type of generator is largely due, is designed to have an output of 10 kilowatts. Designs have been made for a generator of still larger size, with a calculated output of 50 kilowatts and a frequency of 50,000. This machine is intended for trans-Atlantic work.

For some of these machines, instead of driving by gear or steam turbine, a special 2-cycle motor has been devised, to operate at a frequency of 500 cycles per second.

The high frequency alternator method is believed to possess a number of advantages over other methods, inasmuch as it is set in opera-

tion by merely opening a steam valve and has no complicated electrical apparatus or circuits of any kind. The speed is regulated by the steam pressure, this being accomplished by an electrically operated reducing valve.

For measuring the frequency various speed indicators have been tried, but it has been found that the best way is to use a resonant circuit, with an ammeter (shown in plate 11) in it,[a] this being an extremely sensitive means of indicating the frequency, and in addition affording a means of automatically keeping the speed constant to a small fraction of a per cent. The reducing valve is adjusted so that if left to itself the machine will run slightly above speed.[b] As soon as it reaches one-tenth of 1 per cent higher than its designed speed, the resonance begins to fall, and a contact is opened which slightly throttles the steam. In this way the frequency is kept varying between the limits of one-tenth of 1 per cent above speed and one-tenth of 1 per cent below speed. Where the drive is electric instead of by turbine, a storage battery is used to drive the two-phase generator, and even better results may be obtained as regards regulation than with steam.

Transmitters.

The types of transmitters most commonly used are the carbon transmitter and static transmitter, and the carbon transmitter relay.

Plate 10, figure 2, shows the standard type of carbon transmitter.

It was found that the ordinary carbon transmitter was unsuited for wireless telephonic work, on account of its inability to handle large amounts of power. A new type of transmitter was therefore designed, which the writer has called the "trough" transmitter. It consists of a soapstone annulus to which are clamped two plates with platinum-iridium electrodes. Through a hole in the center of one plate passes a rod, attached at one end to a diaphragm and at the other to a platinum-iridium spade. The two outside electrodes are water jacketed.

This transmitter requires no adjusting. All that is necessary is to place a teaspoonful of carbon granules in the central space. It is able to carry as much as 15 amperes continuously without the articulation falling off appreciably. It has the advantage that it never packs. The reason for this appears to be that when the carbon on one side heats and expands the electrode is pushed over against the carbon on the other side. These transmitters have handled amounts of energy up to one-half horsepower, and under these circumstances give remarkably clear and perfect articulation and may be left in

[a] Electrical World and Engineer, November 11, 1899.

[b] Since writing the above, my attention has been called to the fact that the general method of governing by resonance was invented and patented by Kempster B. Miller, United States patent No. 559187, February 25, 1896.

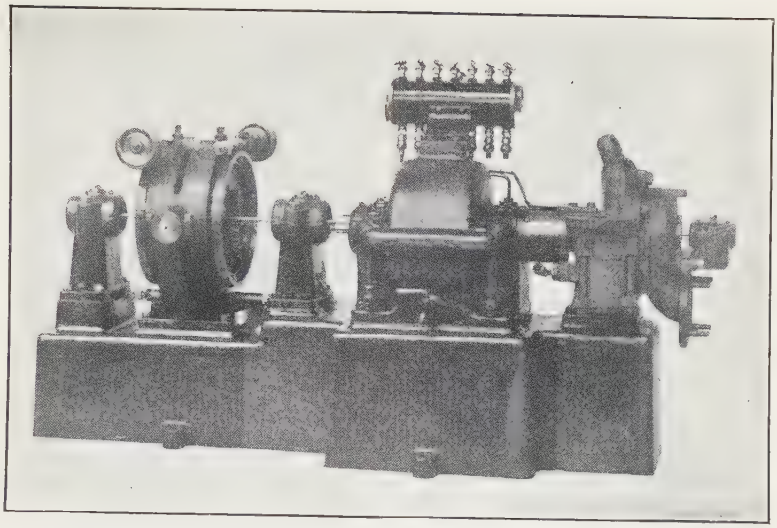


FIG. 1.—TYPE OF HIGH-FREQUENCY ALTERNATOR FOR USE ON SHIPBOARD.

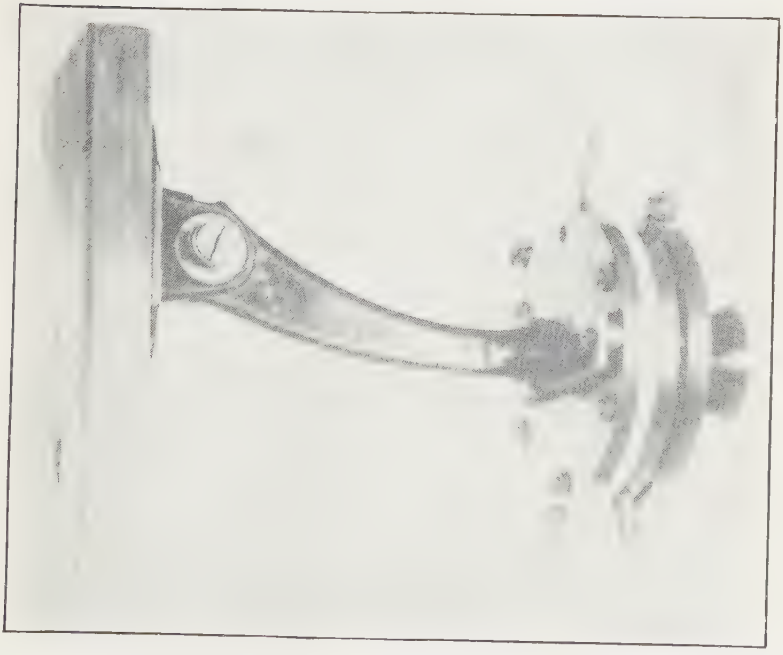
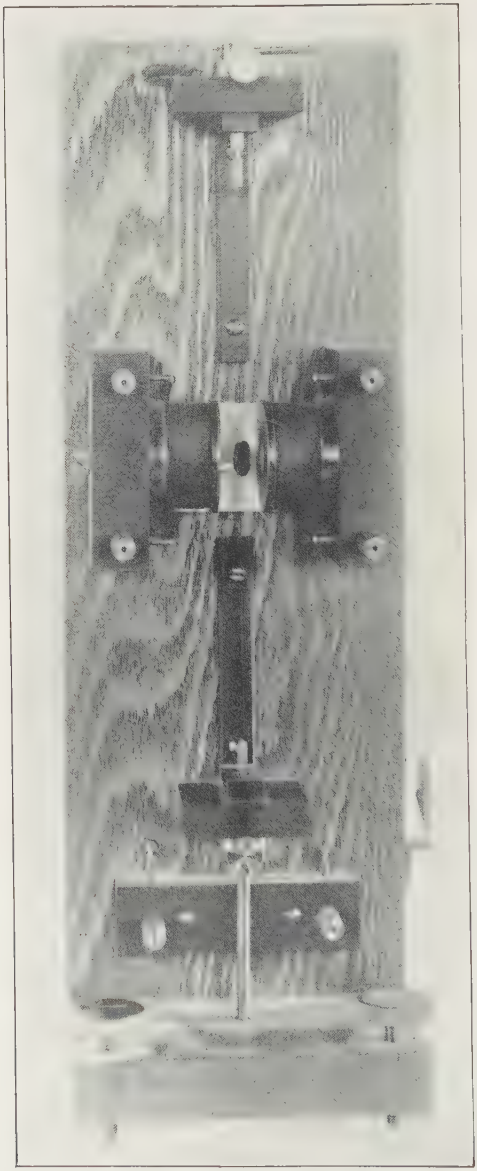


FIG. 2.—STANDARD TYPE OF CARBON TRANSMITTER.



AMMETER FOR INDICATING FREQUENCY AND AUTOMATICALLY REGULATING SPEED.

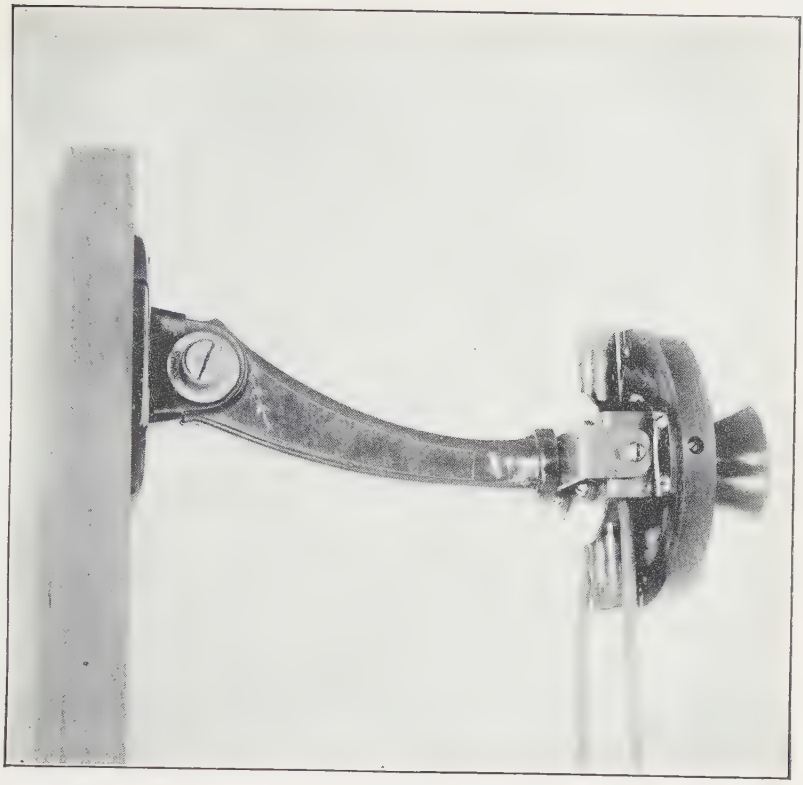


FIG. 1.—MODIFIED FORM OF CARBON TRANSMITTER, WITH SPLIT BACK.

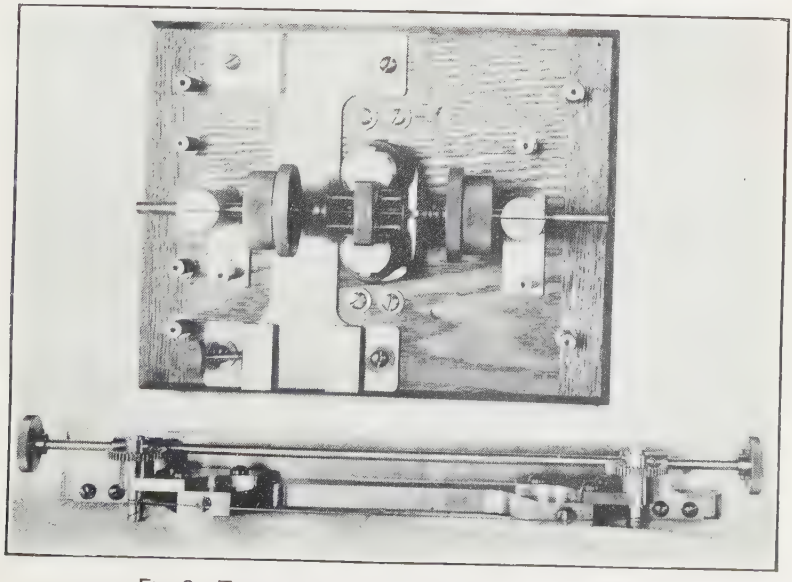
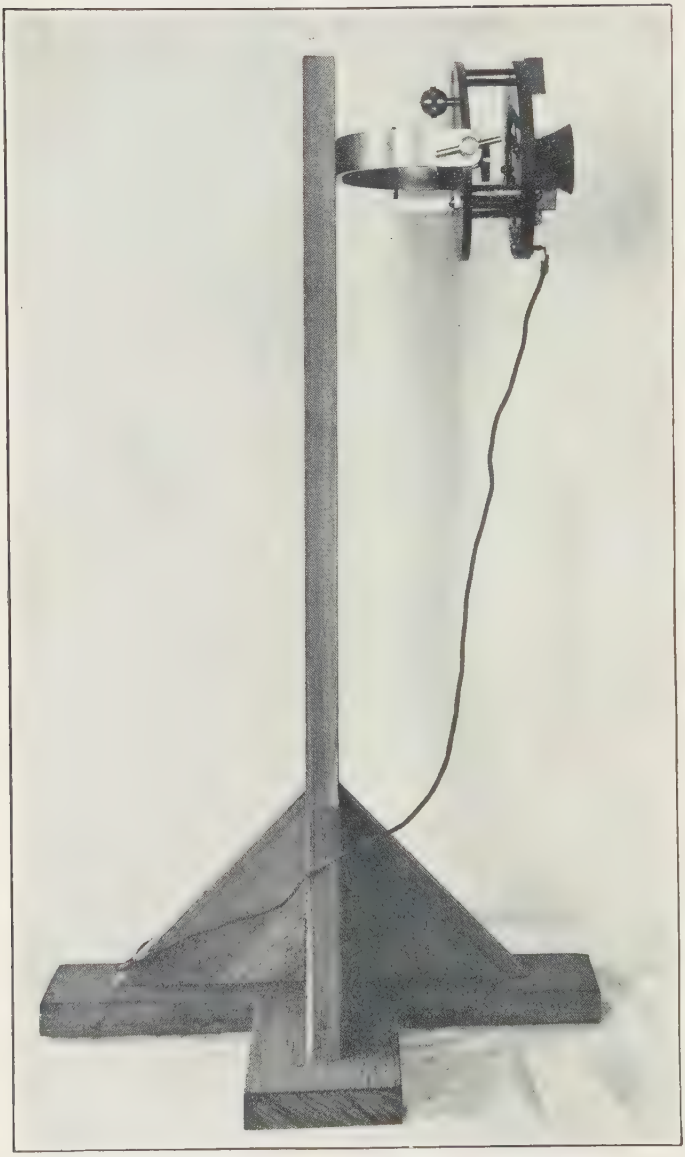


FIG. 2.—TRANSMITTING RELAY FOR STRONG CURRENTS.



FAULTY TYPE OF CONDENSER TRANSMITTER.

circuit for hours at a time. Plate 12, figure 1, shows a modified form with split back.

Plate 12, figure 2, shows a transmitting relay for strong currents. The only thing noticeable about this is that the telephone magnet is a differential one.

Plate 13 shows a type of condenser transmitter in which the vibration of the diaphragm alters the electrical capacity of the transmitter, thus throwing the circuit in and out of tune or spilling more or less energy through a leakage circuit.

Plate 14, figure 1, shows another type of transmitting relay for amplifying very feeble currents. It will readily be understood that where a person in Albany, for example, wishes to talk to another person on board a ship off New York, the wireless station being located near New York, the volume of the transmission received at New York will not be very strong, and while it may be possible to transmit it without amplification, amplification is advisable.

This receiver is a combination of the differential magnetic relay and the trough transmitter. An amplification of fifteen times can be obtained without loss of distinctness. The side electrodes of the trough are water jacketed. The successful amplification depends upon the use of strong forces and upon keeping the moment of inertia of the moving parts as small as possible. Amplification may also be obtained by mechanical means, but as a rule this method introduces scratching noises, which are very objectionable, even though comparatively faint.

Other types of transmitters have also been used, such as liquid jet transmitters, transmitters operating by closing the air gap in a magnetic circuit (plate 15, figure 1), and so changing the inductance of the oscillating circuit, etc.

Plate 14, figure 2, shows a loud-speaking telephone receiver. A small iron disk is placed opposite a nozzle through which air at high pressure is blown. As is well known, this causes the disk to be held close to the nozzle. The telephone magnets alter the position of the disk and thus produce very loud talking.

The transmitting relays are connected in the wire-line circuit in the same way as the regular telephone relay, except that in place of being inserted in the middle of the line they are placed in the wireless station and an artificial line is used for balancing. There is no difficulty met with on the wireless side of the apparatus, but on the wire-line side there are the well-known difficulties due to unbalancing which have not yet been entirely overcome. For the correction of these difficulties, therefore, we must look to the engineers of the wire telephone companies. At present the difficulties are, if anything, less than those met with in relaying on wire lines alone.

Transmitting Circuits.

Figure 2 [a] shows a type of arc circuit.

Figure 3 [b] shows a suitable type of connection for use with a high-frequency alternator.

Figure 4 [c] shows a type of circuit for use with the condenser transmitter.

Figure 5 [c] shows a type of circuit in which the modulation is accomplished by changing the inductance of one of the oscillating circuits.

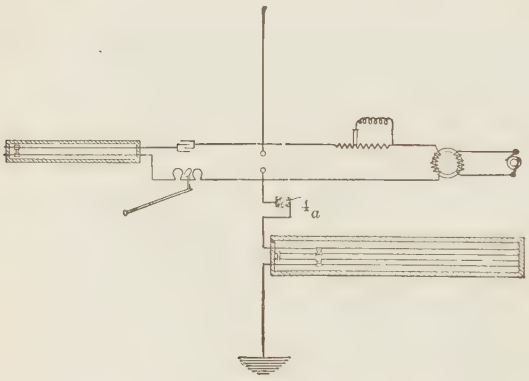


Fig. 2.—Type of arc circuit.

As a matter of fact the transmitter may be placed almost anywhere in the circuit between the arc or dynamo and the antenna, or between the arc or dynamo and ground, or in the transformer circuit, or in shunt to an inductance or capacity, the results obtained in all cases being indistinguishable. The sole criterion of success seems to be that the transmitter should be capable of handling the energy and the circuit should be properly adjusted. Some success has also been attained by placing the transmitter in the field of the dynamo,[d] but this method requires very careful designing of the field circuit.

Fig. 3.—Type of connection with high-frequency alternator.

Receivers.—The receiver which the writer has found most satisfactory for general purposes is the liquid barretter. Plate 15, figure 2, and plate 16, figure 1, show this receiver. It consists of a fine platinum wire, about a ten-thousandth of an inch in diameter, immersed in nitric acid. Tests made with this receiver show that it responds without apparent loss of efficiency to notes as high as 5,000 per second. Some very careful measurements recently made by my assistants, Messrs. Glaubitz and Stein, give the following results:

Voltage of high frequency circuit necessary to produce readable signals, 15×10^{-5} volts.

[a] United States patents Nos. 706742, June 6, 1902, and 730753, April 9, 1903.

[b] United States patent No. 706742, June 6, 1902.

[c] United States patent No. 706747, September 28, 1901.

[d] United States patent No. 793649, March 30, 1905.

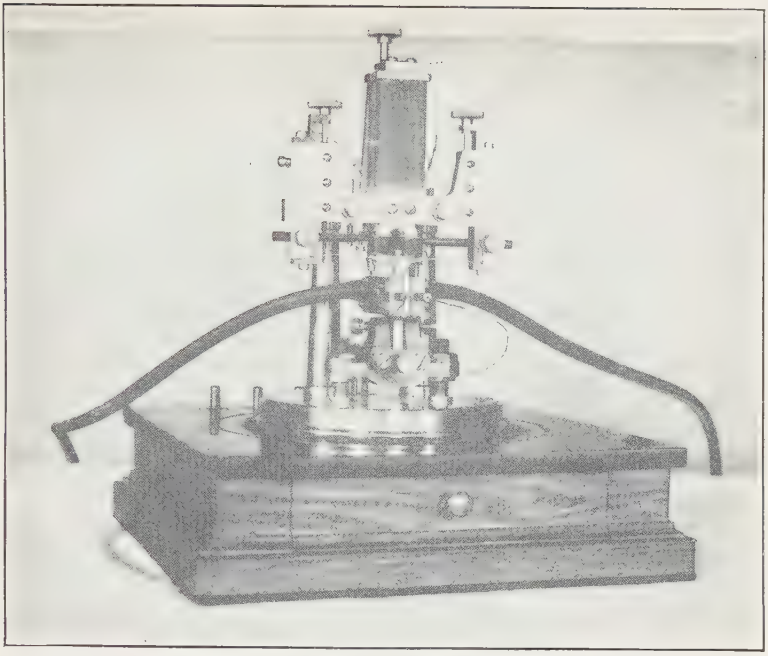


FIG. 1.—TYPE OF TRANSMITTING RELAY FOR AMPLIFYING VERY FEEBLE CURRENTS.

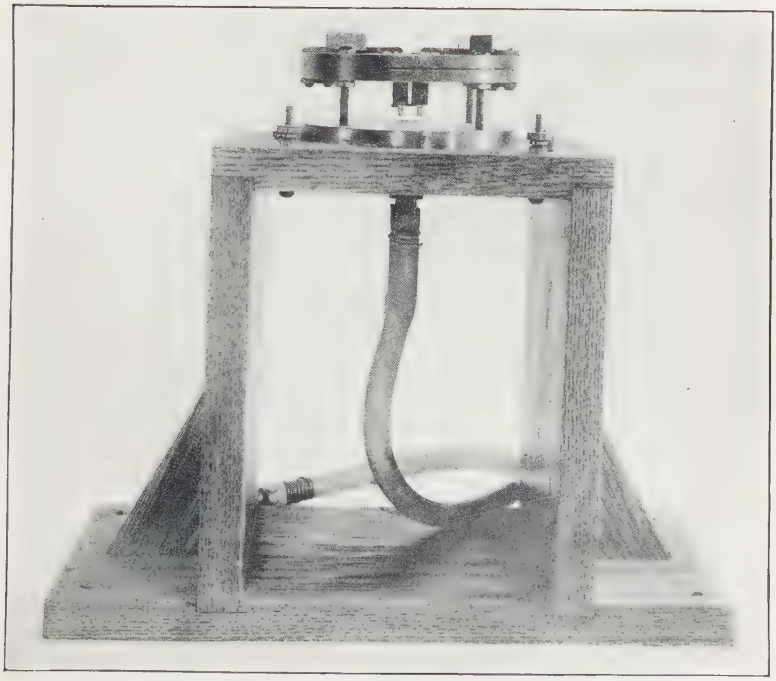


FIG. 2.—LOUD-SPEAKING TELEPHONE RECEIVER.

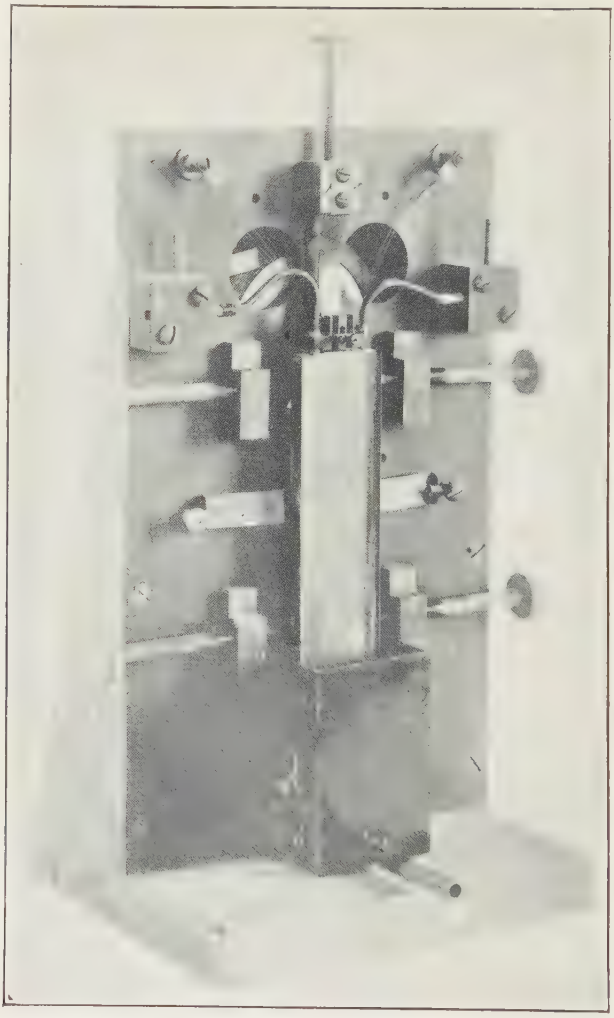


FIG. 1.—TYPE OF TRANSMITTER OPERATING BY CLOSING AIR GAP IN MAGNETIC CIRCUIT.

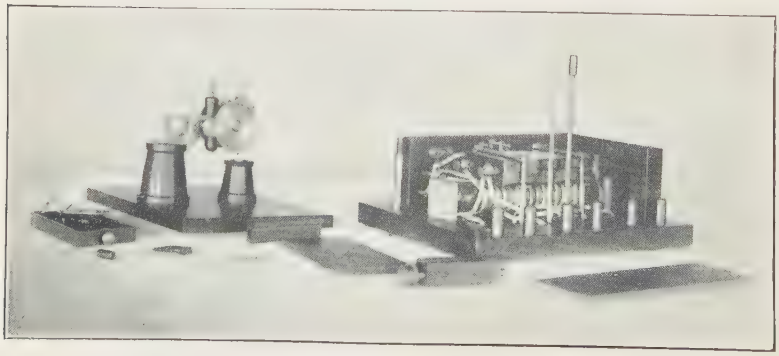


FIG. 2.—LIQUID BARRETTER RECEIVER.

Ohmic resistance of receiver, 2,500 ohms.

Value of high frequency current necessary to produce readable signals, 6×10^{-5} amperes.

Electromagnetic wave energy required to produce audible note for period of one second, 1×10^{-4} ergs.

The telephone used for detecting the signals had a resistance of approximately 1,000 ohms. Some measurements were made to determine the change of current in the telephone circuit by using a sensitive galvometer in series with the telephone, but the results obtained were obviously too low, possibly on account of the electrostatic capacity of the turns of the galvanometer with respect to each other. It will be noted that the amount of electromagnetic wave energy necessary to produce a signal is considerably less than that given in a previous note.[a] The difference is possibly to be attributed to improvements in adjustment and operation.

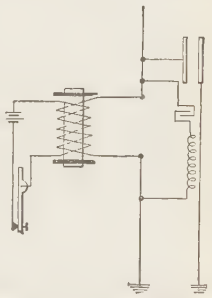


FIG. 4.—Circuit for use with condenser transmitter.

The above measurements were taken by shunting the barretter across a piece of straight resistance wire in series with a hot-wire ammeter, to determine the voltage necessary, and by introducing resistance in series with the barretter to determine the resistance of the barretter. The figures were also checked in a number of other ways and very concordant results were obtained, so that it is believed they may be relied upon.

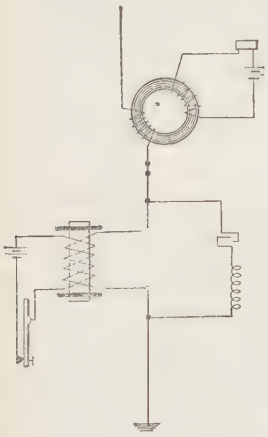


FIG. 5.—Circuit; modulation accomplished by changing inductance of one of oscillating circuits.

The previously mentioned thermoelectric receivers or rectifiers of Doctor Austin and Mr. Pickard, shown in plate 16, figure 2, and the vacuum tube receivers of Fleming, De Forest, and Cooper-Hewitt also act very satisfactorily. The fact that the writer has not been able to get as good results from them may be due to greater familiarity with the liquid barretter and heterodyne receiver.

Plate 17, figures 1, 2, and 3 show forms of heterodyne receiver adapted for use for telephonic work.

Receiver connections.—Where the wireless telephone is operated by first talking into the transmitter and then throwing a switch and listening, the usual wireless telegraphic connections are used. This has been found in practice to be very inconvenient, however, and

[a] Electrical World and Engineer, October 31, 1905.

several methods have therefore been devised for talking and listening simultaneously, which methods can, of course, also be applied to duplex wireless telegraphy. Among these methods may be mentioned the commutator method[a] and the balance method.[b]

The former method is fairly well known and consists in rapidly connecting alternately the transmitter and receiver. The balance method consists in using a phantom aerial as shown in figure 6, where P is a phantom aerial, the circuit having such capacity inductance and resistance as to balance the radiating antenna. The apparatus is shown in plate 18, figure 1.

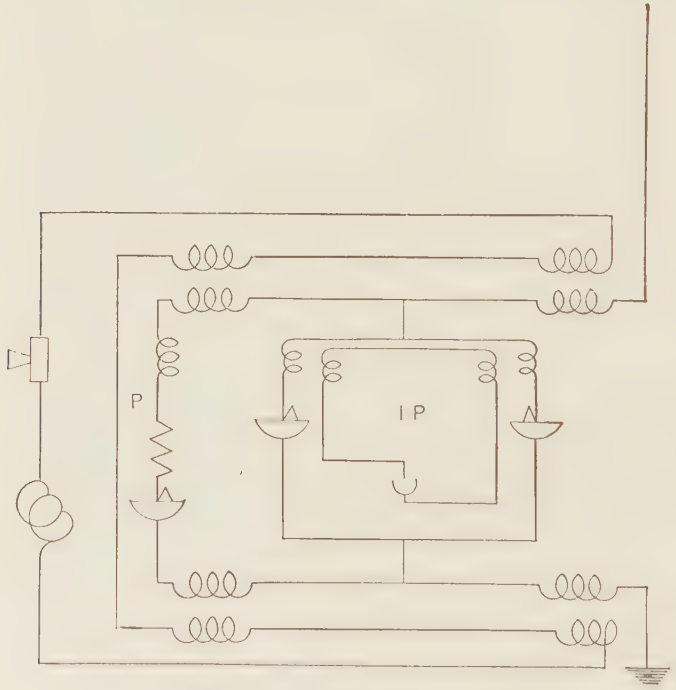


FIG. 6.—Balance method with phantom aerial P.

In order entirely to cut out disturbances in the receiver while sending, an interference preventer, I P, the elements of which are shown in plate 18, figure 2 and plate 19, figure 1, is used in the receiving circuit.

It may be here mentioned that balance methods work much better with wireless telephony and telegraphy than with line telephony and telegraphy, for the reason that the radiation resistance of an antenna is absolutely definite and is not affected by the weather, as are line circuits. Consequently, the balance can be made very sharp and

[a] United States application, No. 350199, December 31, 1906.
[b] United States application, No. 366528, April 5, 1907.

FIG. 1.—LIQUID BARRETTER RECEIVER.

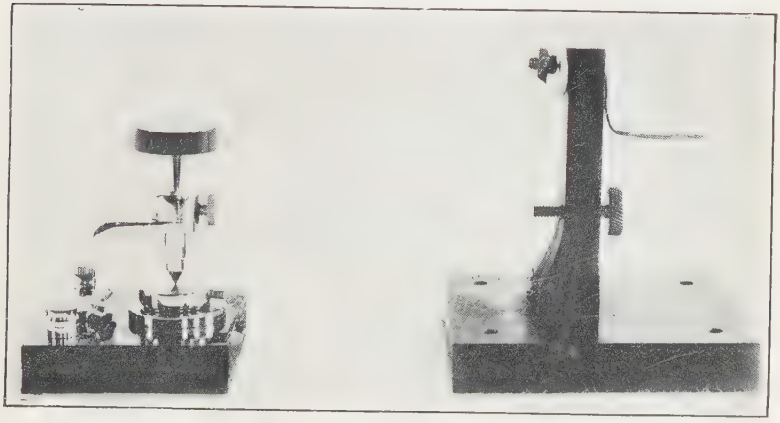


FIG. 2.—THERMOELECTRIC RECEIVERS OR RECTIFIERS.

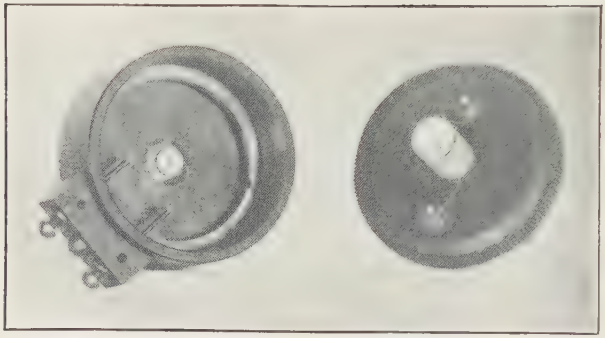


FIG. 1.

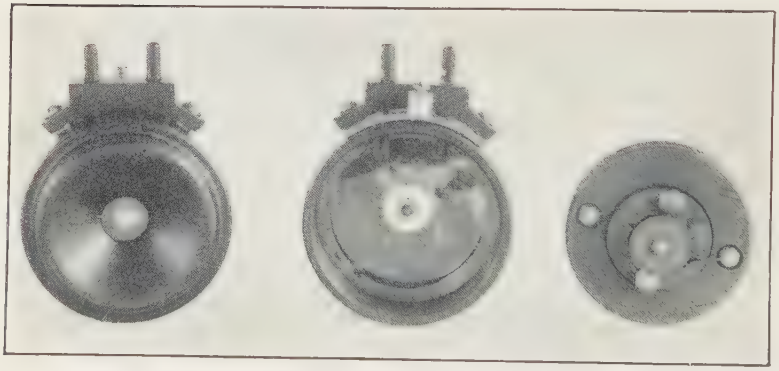


FIG. 2.

FIG. 3.

FORM OF HETERODYNE RECEIVER ADAPTED FOR USE IN TELEPHONE WORK.

FIG. 1.—APPARATUS FOR BALANCE METHOD OF TALKING AND LISTENING SIMULTANEOUSLY.

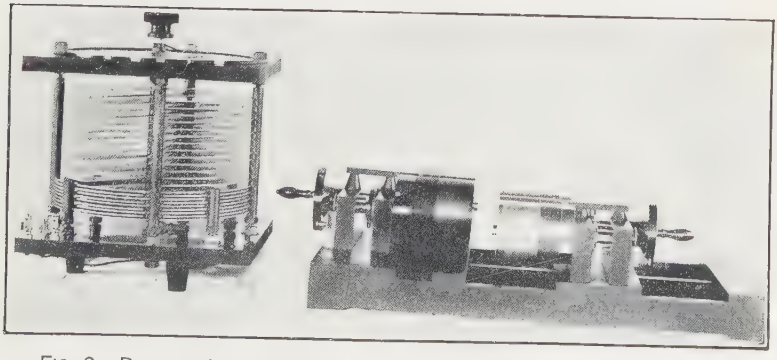


FIG. 2.—PART OF INTERFERENCE PREVENTER TO ELIMINATE DISTURBANCES IN RECEIVER.

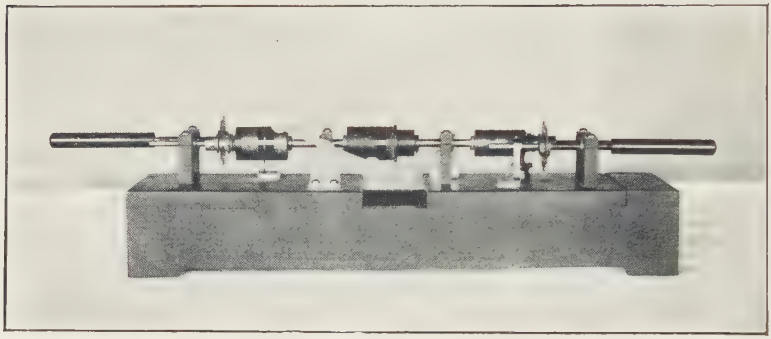


FIG. 1.—PART OF INTERFERENCE PREVENTER TO ELIMINATE DISTURBANCES IN RECEIVER.

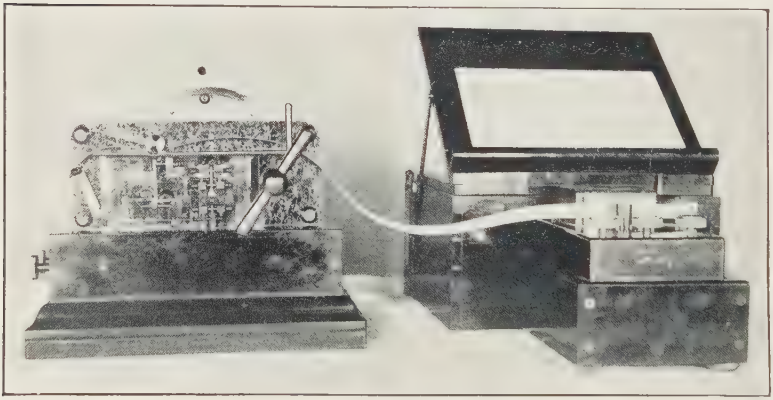


FIG. 2.—WHEATSTONE TRANSMITTER USED IN CAPACITY TEST OF WIRELESS LINES.

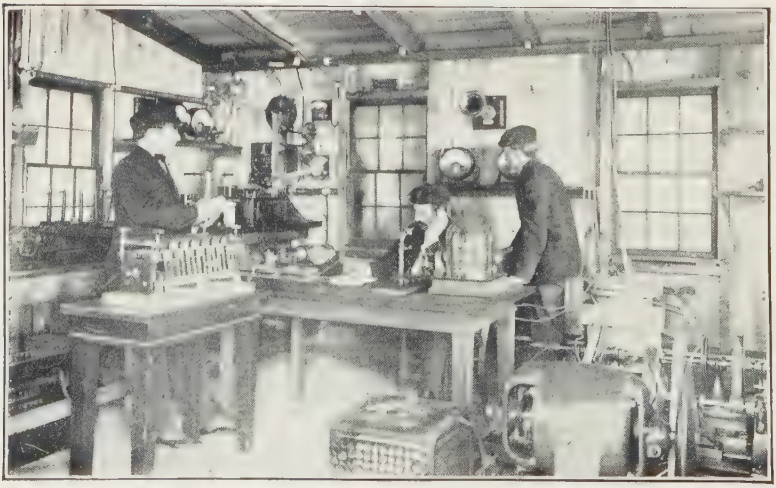


FIG. 3.—TALKING BY RELAYS FROM A LOCAL CIRCUIT.

once made does not need to be altered.[a] Of course, half the energy is lost, but this is a matter of practically no importance, as the cutting down of the strength of a telephonic conversation to one-half is as a rule hardly noticeable, especially where there are no line noises or distortion of the speech through capacity effects.

Receiving station relay.—The receiving station relay is similar to the transmitting relay shown in plate 14, figure 1. The same remarks apply to its use in connection with wire lines as to the transmitting relay.

OPERATION.

As will be realized from the above, the operation of a wireless telephone system is very simple. The operator merely throws his switch to the position for telephoning and talks into an ordinary transmitter and listens in an ordinary telephone receiver. When the duplex method is used, as is always advisable, the conversation proceeds exactly as over an ordinary telephone line. Plate 20 shows a phonograph transmitting music and speech wirelessly. Plate 19, figure 3, shows talking by relays from a local circuit.

I believe I am correct in saying that the transmission by wireless telephone is considerably more distinct than by wire line and that the fine inflections of the voice are brought out much better. This, I presume, is due to the fact that there is no electrostatic capacity to distort the speech, as in the case of wire lines, though I think the effect is also partly due to the absence of telephone induction coils with iron cores. Possibly some of the gentlemen present have witnessed the operation of the wireless telephone transmission between Brant Rock and Plymouth and between Brant Rock and Brooklyn. If so, I think they will bear me out in saying that the transmission was clearer than over wire lines.

As a rule, there is absolute silence in the wireless telephone receiver except when talking is going on, though of course the usual noises

[a] This method may, of course, be used for duplex working in wireless telegraphy. As some question has been raised in regard to the capacity of wireless telegraph lines the writer would say that he has received messages at the rate of 250 words per minute by wireless and is now experimenting with apparatus designed to give 500 words per minute. With duplexing this gives 1,000 words per minute or 60,000 words per hour. The manager of one of the largest cable companies has stated (London Daily Mail, September 24, 1907) that all the trans-Atlantic cables together send 24,000 words per hour. It would appear, therefore, that if capacity alone be considered a single station on each side of the Atlantic can handle more traffic than all the present cables. It should be pointed out, however, that the mere ability to handle the messages is not sufficient and that unless the wireless telegraph companies obtain land facilities equal to those at present enjoyed by the cable companies they can not handle the traffic as efficiently, i. e., can not deliver a message from New York to an individual in London and receive a reply in the same time. Plate 19, figure 2, shows a Wheatstone transmitter used for the test referred to.

may be heard if persons are walking across the room, etc. This makes listening less of a strain than when talking over wire line. Even during severe atmospheric disturbances the talking is not interfered with to any noticeable extent, provided, of course, that an interference preventer is used.

A comparative test was made with talking between Brant Rock and Brooklyn by wireless and by wire telephony. The talking over the wire line was done from a long-distance station in Brooklyn. The wireless transmission was considerably the better. The fact that the wire line included in its circuits a cable from New York to Brooklyn was of course a disadvantage, but even allowing for this, practice and theory appear to be in agreement to the effect that transmission by wireless telephony over long distances is better than by wire line.

This method should be of especial value to independent telephone companies, which have their local exchanges, but no long-distance lines, especially since no franchises or rights of way are necessary.

POSSIBILITIES.

Local Exchanges.

There is no immediate prospect that wireless telephony will take the place of local exchanges. The difficulty in regard to the number of tunes can be overcome, but the fact remains that high frequency oscillations can not be transmitted over wire, and hence each subscriber must have his own generating station. At the present time no method is known which would be practical if placed in the hands of a subscriber. If such means should be found it would be very convenient to call up directly instead of through an exchange, but as I see it there are no immediate prospects of this.

Long-distance Lines.

I believe, however, that there is a field for wireless telephony for long-distance lines. The present long-distance lines are very expensive to construct and maintain, and a storm extending over any considerable section of country inflicts considerable loss on the telephone companies. Moreover, the distance of transmission is limited by the electrostatic capacity of the line, as I understand it. Wireless telephony would have the following advantages:

1. The initial cost would be very much less than that of wire lines.
2. The maintenance would be practically negligible in comparison.
3. In case of any breakdown it would be right in the station and not at some unknown point outside on the line.
4. The depreciation would be comparatively small.
5. The number of employees required would be smaller.

PHONOGRAPH TRANSMITTING MUSIC AND SPEECH WIRELESSLY.

6. The transmission is better, and as there is no distortion of the speech the working distance is, it is believed, considerably greater.

7. The flexibility is greater. With wire lines a telephone company may not be able to give a Boston subscriber a line to New York, while having lines from Boston to Chicago and from Chicago to New York free. Operating wirelesly the wireless circuit normally used for operating between New York and Chicago and between Boston and Chicago could be used to operate from Boston to New York.

8. No right of way need be purchased, and franchises, it is believed, are not necessary.

It will be noted that I have not mentioned any disadvantages of wireless telephony for long-distance work. I presume this is because I am not a telephone engineer. I hope the defects will be discussed by the experts who are familiar with telephone operation and therefore better able to point them out. Before leaving this part of the subject I would say that I think the question of interference has been worked out to such an extent that no serious difficulty need be feared in that direction.

Transmarine Transmission.

Wireless telephony is peculiarly suited for this class of work. Pupin's ingenious and beautiful method has been successful at Lake Constance, Switzerland, I believe, but even assuming that deep-sea cables of this type could be laid and operated successfully, they would nevertheless be very much more expensive than wireless telephone stations. It is believed that wireless telephony will come into extended use for this purpose. Even without further development telephonic communication could be established between Norway or Denmark or Germany or Spain and Great Britain; between Sardinia and Corsica and France and Italy; between France and Algeria; between Australia and Tasmania and New Zealand; between the United States and Cuba and Porto Rico, etc., were it not that it is at present forbidden by law.

As regards telephonic communication between England and America, my measurements show that this should be possible with an expenditure of approximately 10 kilowatts and suitably large towers, say 600 feet high, or with some of the new forms of antenna. Whether such a transmission would be commercially valuable or not is another matter. Personally I do not see that it would, but when I remember that at the time when the telephone was first being introduced a number of eminent business men decided that the house-to-house printing telegraph would be more of a success commercially than the telephone, for the reason that no one would want to do business unless he were able to have a record of the transaction, I must admit that there is a possibility of my being mistaken in this.

Wireless Telephony from Ship to Ship.

Here, of course, wireless telephony occupies a unique position. Wireless telegraphy has the disadvantage that a telegraph operator must be carried. The additional expense is an objection in many cases. The proposition that the captain or mate should also be a telegraph operator has not met with favor. Anybody, however, can operate the wireless telephone and almost every vessel carries an engineer capable of repairing the electrical apparatus in case of accident. The final arrangement will, I believe, be this; that passenger vessels will carry a telegraph operator and use the telephoning apparatus for ordinary work and for telegraphing where it is desired to communicate over long distances. Other vessels will use the telephone alone.

Wireless Telephone from Ship to Local Exchange.

This also will, I think, have considerable value, as enabling the captain of a vessel to communicate, by relaying over the wire line, with the owner of the ship, or enabling a passenger on a vessel to communicate with friends on shore.

Range of Wireless Telephony.

atmospheric absorption.

The great obstacle to long distance wireless telegraphy and telephony is atmospheric absorption. For short distances up to 100 miles in the Temperate Zone there is little difference between the strength of the signals at one time of the day and another. As soon as the distance is increased much over 100 miles for the Temperate Zones and 40 or 50 miles for the Tropics the signals at night are very irregular and there is great absorption during the daytime. The daylight absorption may be so great that less than a tenth of one per cent of the energy transmitted gets through. Some nights will be as bad as daytime, while on other nights there will be apparently no absorption.

Figure 7 is a curve showing the strength of the messages transmitted between Brant Rock, Massachusetts, and Machrihanish, Scotland, at night, during January, 1906. Nothing at all was received that month during daytime.

The change in the strength of the signals is very sudden. In working from Brant Rock to Porto Rico, a distance of 1,700 miles, the strength of the signals with short wave lengths would fall off to one one-thousandth of their former value during a period of less than fifteen minutes, while the sun was rising.

Early experiments showed that the absorption was greater as the wave length was increased and the effect was at first attributed to absorption in the neighborhood of the sending station, and was

thought to increase continuously with the wave length.[a] This fluctuating absorption at one time appeared to place a fundamental obstacle to commercial wireless telegraphy, as telegraph engineers will easily appreciate the impossibility of operating telegraph systems with circuits where the strength of the received signals may fall to one thousandth of its value or rise to a thousand times its value in the course of a few minutes.

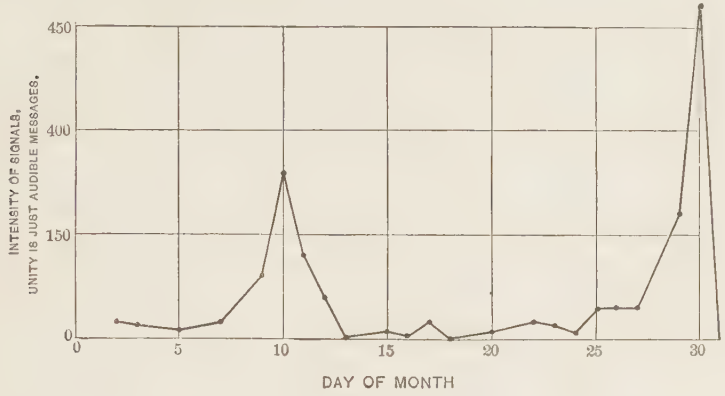


FIG. 7.—Curve showing variation of intensity of transatlantic messages for the month of January, 1906.

It was therefore considered absolutely essential, in order to decide whether long-distance wireless telegraphy was commercially possible or not, to investigate this phenomenon fully. As a preliminary, the station at Brant Rock sent signals to four or five other stations at varying distances and comparative readings were taken. The following table shows the general character of the results obtained:

Station.	Distance.	Strength of signals received on worst nights.[a]
Company's cottage	200 yards	1,000
Lynn	30 miles	1,000
Schenectady	170 miles	500
Philadelphia	270 miles	300
Washington	400 miles	150
Machrihanish	3,000 miles	1

[a] Strength of unabsorbed signals taken as 1,000.

These experiments proved conclusively that the absorption did not take place in the neighborhood of the sending station, because

[a] A mathematical explanation of this supposed fact was given by Doctor Fleming, Principles of Electric Waves Telegraphy, pp. 617–618, 1906, the following conclusions being reached:

"Accordingly, the chief part of the weakening of the wave by sunlight is done in the neighborhood of the sending antenna, where the magnetic force H is greatest, and it is more sensible for long and powerful waves than for short and feeble ones. This agrees with the observations of Mr. Marconi."

the strength of the signals received at near-by stations was the same during the day as during the night, while there was great variation in the strength of signals received at stations farther away.

It was also found that the absorption at a given instant was a function of the direction as well as of the distance, since on a given night the signals received by stations in one direction would be greatly weakened, while there would be less weakening of the signals received by stations lying in another direction, while a few hours or a few minutes later the reverse would be the case.

This was thought to be connected with the coming weather conditions, but before this fact is proved a much larger amount of data must be collected. Through the kindness of the United States Weather Bureau I was enabled to obtain a chart of the magnetic variations, and on comparison of these with the absorption between the Massachusetts and Scotland stations there appeared to be a quite definite relation, i. e., the greater the absorption the greater the magnetic variation. Here also, however, much more data is needed before arriving at a definite conclusion. The fact that the absorption did not take place in the neighborhood of the sending station having thus been definitely settled the next point to be investigated was whether or not there was any way of overcoming it.

The fact that variations in the absorption occurred with extreme rapidity, the absorption increasing sometimes a hundred fold in a single minute, and at night, when the effect could not be due to the sun directly, seemed to indicate that the body producing the absorption, whatever it was, was not in a state of continuity, but was broken up into masses like clouds.[a] This also was in accordance with some experiments made in Brazil in 1905.

From optical theories it is known that where the absorption is produced by conducting masses of a more or less definite size the absorption is to a certain extent selective. The next point in the investigation was, therefore, to determine whether there was any possibility of this being the fact in the case of the absorption of wireless signals.

Comparative tests were therefore made of the absorption at night and during the day between Brant Rock and Washington, with wave lengths varying from a fraction of a mile up to four or five miles. It was found that the absorption did not increase continuously with the wave length, but reached a maximum and then fell off with great suddenness.

Figure 8 shows the general character of the curve, the ordinates referring to the amount of the absorption and the abscissas to the wave frequency.

[a] Electrical Review, May 18, 1906.

It may be noted that the absorption is a maximum at a frequency of about 200,000 per second, nine hundred and ninety-nine thousandths (0.999) of the energy being absorbed at this frequency during daylight, while for a frequency of 50,000 the absorption does not appear to be appreciable. Longer experiments, of course, might show some absorption, but in any case it is of a different order from the absorption for the shorter wave lengths.

Experiments were then made between Brant Rock and the West Indies, a distance of 1,700 miles, during the spring and summer of 1907. It was found that the results were of the same character, i. e., that while there was greater absorption for frequencies of 200,000 there was comparatively little absorption for frequencies in the neighborhood of 80,000, and messages were successfully transmitted in daylight with this latter frequency. No messages were received in daylight with the higher frequency, though messages transmitted from the same station and with the same power and frequency were

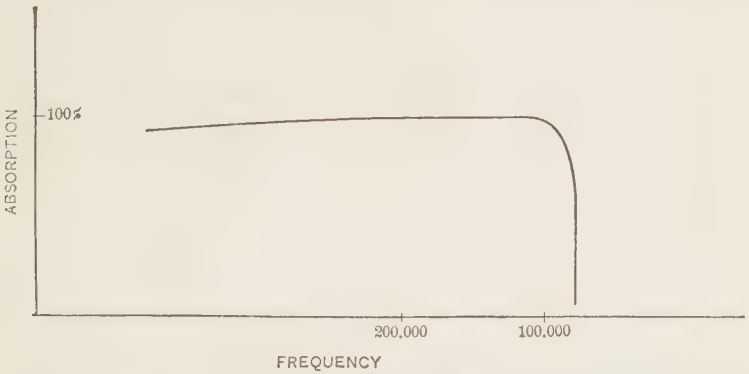


FIG. 8.—Absorption curve, tests between Brant Rock and Washington.

officially reported as having been received at Alexandria, Egypt, a distance of approximately 4,000 miles.

The fact that these experiments were made during summer weather, and the receiving station was in the Tropics, and the fact that the distance, 1,700 miles, was practically the same as that between Ireland and Newfoundland, definitely settled the question as to whether long-distance wireless telegraphy was a commercial possibility or not, and the results were therefore published.[a]

Since the publication of the above results, transmission has been accomplished by means of these long waves over still greater distances during daylight. Mr. Marconi, early in October, 1907, abandoned the short-wave lengths previously used and adopted one over two units in length, and immediately succeeded in operating between

[a] The Electrician (London), July 26, 1907.

Glace Bay, Nova Scotia, and Clifden, Ireland, a distance of more than 2,000 miles, the frequency being approximately 70,000. The same messages were received at Brant Rock, Massachusetts, a distance of nearly 3,000 miles.

Still more recently Captain Hogg, of the "Glacier," has written that during the southward passage of the Pacific fleet he received messages from the station at Brant Rock, Massachusetts, while off Cape Ste. Roque, Brazil, South America. The frequency used for sending was approximately 80,000, and the messages were received with the very interesting and sensitive silicon receiver invented by Mr. Pickard. This distance of 3,000 miles is the greatest yet achieved by wireless transmission during daylight, and would indicate that with the use of suitable high towers much longer distances can be reached.

RANGE OF WIRELESS TELEPHONY AND WIRELESS TELEGRAPHY COMPARED.

For the same power it is possible to telegraph to a farther distance than to telephone. Distinct speech depends upon the presence of harmonics of a frequency as high as 1,200 per second. The amplitude of these harmonics is, according to some rough experiments made by the writer, only about 1 per cent of the fundamental frequency. Consequently, with a perfectly modulated transmitter, one hundred times as much energy would be necessary to telephone a given distance as to telegraph. It fortunately happens, however, that a carbon transmitter and also the circuits in which it is used, can be so constructed as not to modulate perfectly, but can be arranged so as to accent the higher harmonics.

With transmitters arranged for the purpose good transmission has been obtained with thirty times the energy required to produce audible telegraphic signals. By still further modification the power required has been reduced to approximately ten times that necessary for telegraphing, curiously enough without noticeably distorting the character of the speech. There is one fact, however, which prevents the ratio from being as large practically as the instruments show, i. e., speech can be satisfactorily understood with a less increase of power above a minimum audibility than telegraphic signals.

The amount of power necessary for wireless telephony may therefore be taken as approximately five to fifteen times that necessary for wireless telegraphy, i. e., under the same circumstances and for the same power the wireless telegraph will carry two to four times as far. The difference in range would be very much greater also but for the curious fact that there is much less falling off with sustained oscillations than with intermittent groups of waves, even though the frequencies are identical.

This fact has been repeatedly determined by sending between Brant Rock and Brooklyn on the same frequency, using in the one case spark-produced trains of waves and in the other the high-frequency dynamo. The difference in the falling off for the same frequency and energy is very great, but further work is necessary before anything very definite can be said about it or the reasons finally determined. * * *

[Mr. Fessenden concludes his article with a discussion of the difficulty of securing governmental authority and legislation for the development and operation of wireless telegraph systems by private corporations.]

PHOTOTELEGRAPHY.[a]

By Henri Armagnat,
Consulting engineer, expert for the Tribunal Civil de la Seine.

The transmission of pictures to a distance by the electrical current is not a new idea. It had its inception perhaps some thirty years ago when electricity itself was developing, and even then furnished ground for hopes which are to-day partially realized. The invention of the photophone by Graham Bell had made generally known the sensitiveness to light of selenium, and its utilization for the transmission of pictures was at once proposed by many. These attempts were unsuccessful. Indeed, during the last thirty years no further advance has been made in the direct reproduction at a distance of the images of real animate objects.

But if we restrict our problem to requiring electricity to send and reproduce, point by point, an inanimate picture, we shall find several interesting solutions, some of which have had practical trials and require but little further development to be commercially practicable whenever a demand for phototelegraphy grows.

The transmission of pictures containing only blacks and whites without any half-tones was tried in 1851 by Backwell, in 1855 by Caselli, and finally by d'Arlincourt in 1872. All these inventors had in view not the sending of a picture, but the transmission of writing. Their purpose was to send autographs by means of the telegraph, but they naturally could have reproduced equally well other pen designs. As the phototelegraphy of to-day still embodies these early ideas, it is really no innovation.

In order to reproduce in B an image, A (fig. 1), it suffices to move over A a style, *a*, so that it follows successively a series of very close parallel lines, while by some suitable means a second style, *b*, follows upon the receiver, B, traces similar to those upon A, occupying at each instant a position upon B similar to that which *a* has upon A.

[a] Translated, by permission, from the Revue Scientifique, April 18, 1908; fifth series, Vol. IX, No. 16, Paris, 1908.

The two styles thus work synchronously. If now we so devise our apparatus that when *a* reaches a black portion of its image, the style, *b*, marks upon B a black trace, then, when sufficient time has elapsed for the style to have run over the entire image, we will have in B a reproduction of A, except that the latter will consist of a series of points and parallel traces, and so will not have the continuity of the original image.

The ever-increasing use of the processes of photo-engraving has accustomed us to such discontinuities and, provided the parallel traces are not too far apart, experience has shown that the reproduction will be very satisfactory.

Let us consider the methods used to produce the synchronism. The phototelegraphic apparatus for which the processes have been the most developed in this respect make use of an early conception used by d'Arlincourt and which has now been carried to a very high point of precision in certain actual telegraphs such as that of Baudot. The device used is as follows: The sheets, A and B, are rolled upon rotating cylinders. The cylinder of the receiver, B, turns a little faster than that of A, but the advance made each turn is too small to produce a sensible distortion of the image. In order to perfect the synchronism, it is sufficient to stop the cylinder, B, a very short time until the cylinder, A, turns to the corresponding position. At that moment a contact, controlled by A, sends through the line connecting the two stations a current, freeing B, and the two cylinders start simultaneously from the corresponding parts at each turn. This device avoids the accumulation of small errors in the speeds of the two cylinders, and the resulting image is practically satisfactory. The speed of rotation of B is so adjusted as to be a half or one per cent faster than that of A and the moment of correction is so chosen that it always falls somewhere on the margin of the paper where no part of the picture is to fall.

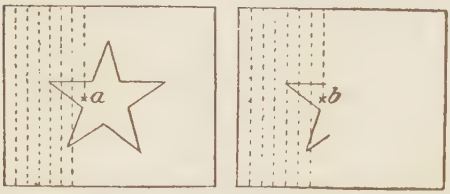


FIG. 1.

The styles marking on the cylinders would always trace the same circumference if they were not made to advance gradually toward one side. This movement is impressed by means of a screw parallel to and whose motion is controlled by the cylinder. A nut mounted on the screw carries the style and as this nut is kept from turning, the style must advance. The combination of these two movements, the rotation of the cylinder and the advance of the style, causes this style to explore successively all points of the picture.

So much for the past. Let us now see how the modern inventor has solved the many other difficulties. Professor Korn, of Munich, alone makes use of selenium; all the others use some mechanical device.

KORN'S APPARATUS.

This apparatus is represented in figure 2, in the form in which it was tested in Paris, by the journal "l'Illustration," in February, 1907. Since then the scheme has been altered as shown in figure 5, but this modification, interesting in practice, really offers no real change in the mode of operation, so we will use figure 2 for describing this process.

At the transmitting station, the picture to be reproduced is in the form of a photographic film rolled upon the cylinder of glass, *a*. This cylinder is run by an electric motor through the tangent screw and wheel seen at the upper part. The farther metallic end of the cylinder forms a nut working on a vertical axis so that as the cylinder turns it mounts or descends. Under the cylinder is placed the essential organ of the transmitter, the selenium cell. A source of light, *b*, placed at the side, sends a bundle of rays upon the lens, *c*, which focuses them upon a point of the photographic film; these rays traversing the picture are more or less weakened according to the opacity of the film at that point; the transmitted light diverges and is received by a prism, *d*, which reflects them to the selenium cell, *e*.

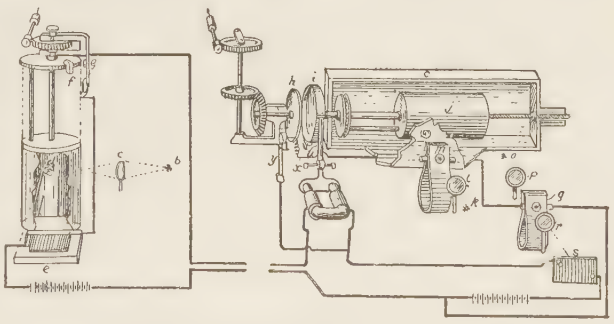


FIG. 2.—Korn's apparatus.

It is easily seen that, because of the motion of rotation and the progression of the cylinder, all points of the picture pass successively under the concentrated pencil of light, and the selenium cell is continuously acted upon by the successive variations in the intensity of the light. Selenium, when it is in the suitable allotropic state, offers a much greater resistance to the passage of an electric current when in the dark than when exposed to the light or heat. Consequently, if the selenium cell is placed in a telegraph line with a battery, the strength of the current received at the other station will show at each instant the opacity of the point of the image then passing under the pencil of rays, and it remains only to utilize the variation of this cur-

rent for reproducing at the receiving station the image at the sending station.

We will not describe here the device used by Korn for making manifest this image. He used the cathode rays produced by currents of high frequency and a very sensitive galvanometer. This very ingenious receiving device was, however, too delicate for ordinary practice and is to-day replaced by a much simpler and rougher apparatus.

The current sent by the transmitter passes through a string-galvanometer, which is made to more or less obscure a window, *m*, through which a luminous pencil of rays, emanating from the lamp, *k*, and concentrated by the lens, *l*, enters the dark chamber which holds the receiving cylinder, *j*. The latter turns upon its axis similarly to the transmitting cylinder and is covered with a sensitive photographic film. The lamp, *k*, and the lens, *l*, are so placed as to produce upon this film a very minute point of light; the varying diaphragm carried by the string-galvanometer renders the intensity of this point of light proportional, or inversely proportional, to the current coming over the line, and consequently to the opacity or transparency of the corresponding point of the image we wish to reproduce. The impression upon the film varies with regard to the original image according to the mode of disposition of the diaphragm so that it is possible to obtain a positive or negative reproduction. It remains only to develop the film to have the complete reproduction of the image sent over the line.

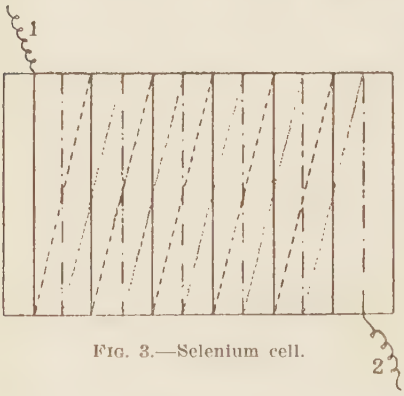


FIG. 3.—Selenium cell.

Figure 2 indicates the device used for the synchronism: The lever, *u*, passes very close to the disk, *i*, and stops that disk when *u* hits the spur, *x*; as the movement from the electric motor is transmitted to the cylinder through a friction clutch formed by the cone, *h*, and the box, *i*, the motor continues to turn; as soon as the transmitting cylinder, *a*, comes to the proper point, the finger, *f*, will touch the spring, *g*, breaking the current which traverses the electro-magnet, *t*; the latter frees its armature, the lever, *u*, comes away from *i*, freeing the cylinder which then resumes its rotation. The same course of events recurs at each turn of the cylinder, correcting the small variations in its speed, provided only that the receiving cylinder, *j*, turns a little faster than the transmitter, *a*.

Let us examine some further details of the apparatus. The selenium cell is formed of a little slab of stone or slate, figure 3, upon which

are wound, parallel and insulated from each other, two fine platinum wires, 1 and 2. Upon one face this slab is covered with a very thin coat of selenium so that these two platinum wires are now connected through the selenium and this separating resistance can be doubled or even more than doubled by removing the cell from the light to darkness. It is also extremely important to protect these cells from the ordinary variations of temperature during an experiment as their resistance varies from both light and heat.

The string-galvanometer used by Korn is a very recent device and was first made a few years ago by Ader as a receiver for submarine telegraphy. It possesses a very great sensibility and Einthoven has since constructed one which will detect currents of the order of 10^{-12} amperes—a millionth of a microampere. Reduced to its simplest, schematic form, the string-galvanometer consists of a thin conducting thread, *f* (fig. 4), stretched between two fixed points, *a* and *b*, and passing between the poles, PP, of an electro or a permanent magnet. A current passing through this thread causes it to bend in a direction perpendicular to the lines of force of the field and this deflection is observed with a microscope whose axis coincides with the direction of the field. Einthoven used a thread of silvered quartz having a rather large electrical resistance and a long period of oscillation. Korn constructed it of bronze, and as it must carry the diaphragm used for varying the light, it had rather large dimensions.

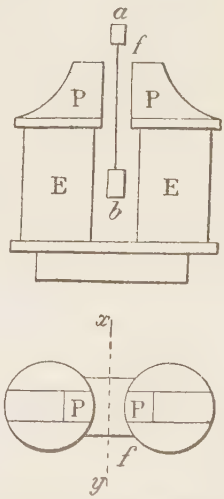


FIG. 4.—String-galvanometer.

In the first trials Korn, as did all those who had preceded him, used the total variation of the resistance of the selenium, but he early saw it was impossible to obtain in that way rapid signals on account of a certain inertia which the selenium had in following the variations of resistance impressed upon it by the light. The resistance of the selenium at each instant depends not only on the illumination to which it is then exposed, but as well upon its previous illumination, and if we wish the cell to return to its normal resistance in the dark it must be given a considerable time. Korn overcame this difficulty through a method of compensation which used the small differential variations in the resistances of two cells—one, *c*, which is a part of the transmitting system and is submitted to the direct action of the light (fig. 2), the other which serves in the receiver and is placed before the auxiliary lamp, *o*, the intensity of the light of which is varied by the string-galvanometer, *q*.

The plan of the apparatus (fig. 5) will show how this compensation takes place. Two selenium cells, Se_1 and Se_2, form two branches of a Wheatstone's bridge, the resistances, A and B, serving for the other two arms. A battery furnishes the current through two opposite junctions of the bridge, the line and the galvanometer being connected to the two remaining junctions. The cell, Se_1, is placed in the sending apparatus; it is exposed directly to the light transversing the picture which is to be transmitted; the cell, Se_2, is lighted by an auxiliary source, obscured by the galvanometer, *g*, and the apparatus is so devised that as Se_1 receives light, the equilibrium of the bridge is broken; but the galvanometer, *g*, in deviating uncovers more or less the auxiliary beam so that Se_2 becomes illuminated and tends to reestablish the equilibrium. The galvanometer of compensation and the receiver, G, receive the same current. The difference between figures 2 and 5 is that, in the working apparatus, the cell and the compensating galvanometer are both at the transmitting station.

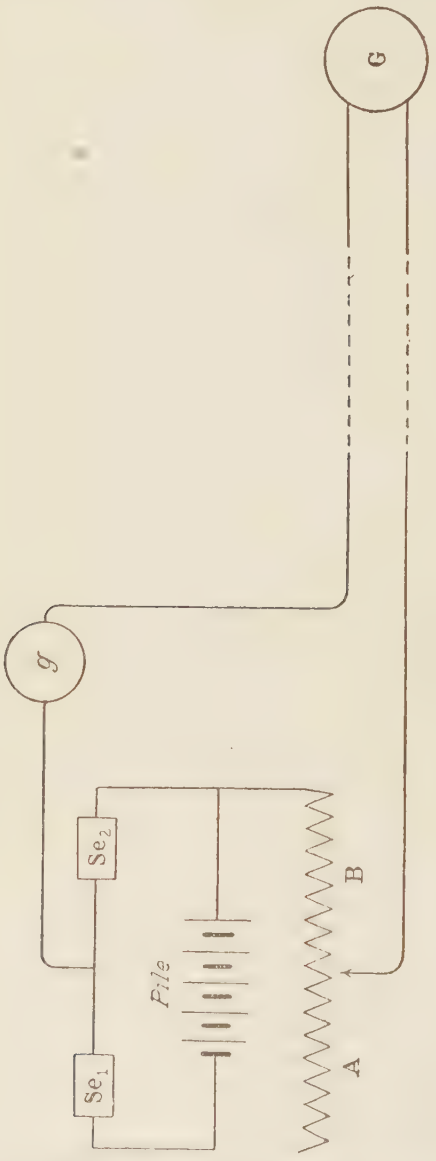


FIG. 5.—Korn's apparatus, later form.

The Korn system is the only one which has been practically tried with the transmitter separated from the receiver. In the trials between Munich and Berlin, during the year 1907, the transmission of a picture 130 by 240 millimeters, reduced to approximately 35 by 64 millimeters at the receiving station, was accomplished in six minutes. These trials were made over a double telephone line and at night in order to avoid the disturbances produced by the neighboring lines.

THE TELESTEREOGRAPH OF BELIN.

The system of Belin is far simpler and requires, besides photography, only purely mechanical devices, such that in the trials, although they were only local and with no attempts at synchronism, it was possible for him to furnish more practical results than those obtained by Korn, despite the ingenuity and the much-praised devices of the latter.

As we have just said, Belin did not wish to complicate his experiments with the problems of synchronism, knowing that there now exist many tried means of solving that part of the problem, and he contented himself with coupling mechanically the transmitter and the receiver side by side.

The picture to be transmitted is reproduced upon a bichromate gelatin film. Reproductions of this kind are known to be much thicker where the light has acted the most intensely, and consequently a photograph on such a bichromate gelatin film has a variable relief. This property has, indeed, been made use of in some of the processes of photo-engraving.

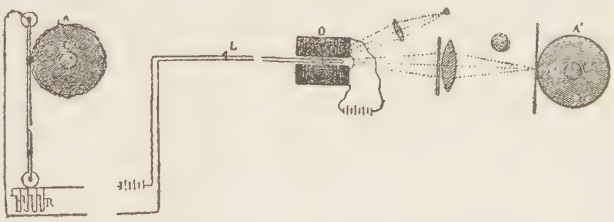
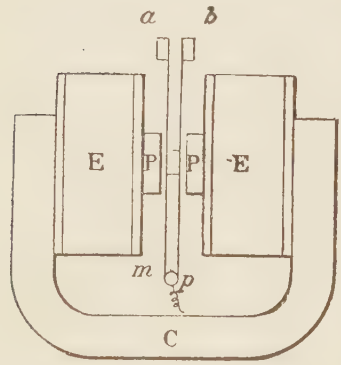


FIG. 6.—Belin's apparatus.

The bichromatized-gelatin film is rolled at G (fig. 6) upon a cylinder, C, which has a double movement of rotation and translation as in the preceding apparatus. A lever, jointed at its upper part, carries a style analogous to those used with phonographs, and resting firmly upon the film, follows all the reliefs of the latter. These displacements of the style are magnified eight times by a lever near its lower extremity; the end of this lever forms a minute contact which moves over the bars of a rheostat, R. The circuit incloses a battery, the rheostat, R, the line and the receiving apparatus. According to the value of the relief at the point touched by the style, the resistance taken from the rheostat is more or less great, and so the intensity of the current in the line varies. At the receiving station the apparatus consists of a galvanometer, O, whose mirror receives light from a lamp. The pencil of rays reflected from the galvanometer falls upon a lens so placed that the light which traverses it is always brought to a focus at the point, F, upon the photographic film, A. Before the lens there is placed a screen, T, composed of twenty strips of increasing capacity, called by Belin a "gamut of tints." According to the deflection of the galvanometers, that is to say, according to the

intensity of the current coming over the line, the luminous pencil traverses a part more or less opaque of this "gamut of tints" and the intensity of the light at F consequently varies. According as the reflected ray passes through a dark or clear part of the "gamut" when the style of the transmitter is upon a thin or white portion of the film will the result be a positive or a negative.

The cylinder, C′, of the receiver is inclosed in a dark chamber and covered with a sensitive film. A metallic screen, pierced with a hole one-sixth of a millimeter in diameter, is situated at F and limits the extent of the film acted upon by this light. And finally, in order to avoid the phenomena of diffraction, this pierced, metallic screen touches closely the sensitive surface of the film. The reproduced image is formed by the juxtaposition of short lines one-sixth of a millimeter in breadth.



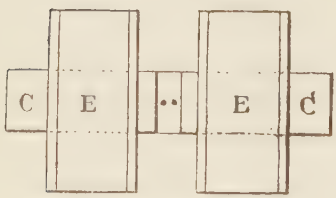


FIG. 7. —Blondel's oscillograph.

We would call attention to two special features in the apparatus of Belin. The rheostat, R, is composed of 20 resistances, the values of which are calculated with due allowance for the resistance of the line so that a proper variation of the current will be reproduced. These resistances are connected to a little commutator composed of 20 laminæ of silver, separated by leaves of mica. This assembly possesses a thickness less than $3\frac{1}{2}$ millimeters; upon the surface of these laminæ works the contact of the lever which is actuated by the relief of the bichromatized gelatin film of the cylinder, C. This piece plays an important rôle and is a most delicate part of the apparatus to construct.

In order to obtain a rapid transmission of the signals it is necessary to use a galvanometer, at the same time very sensitive and of a very short period of oscillation. Belin employed an instrument somewhat widely used to-day in laboratories, the oscillograph of Blondel. This apparatus, represented schematically by figure 7, consists essentially of a flat, extremely fine wire attached between two fixed points, a and b, and stretched at its lower end by the pulley, p, which is attached to a spring. The whole of this is placed between the poles PP, in the very intense magnetic field produced by the electro-magnet EE. When the current mounts in one of the blades

and descends in the other, one of the blades tends to displace itself perpendicularly to the plane of the figure forward, and the other backward; this causes a rotation of its mirror and it is this latter movement which is used for sending the reflected beam of light upon the suitable part of the "gamut of tints." In order to have a more exact idea of the dimensions of this galvanometer, let us suppose that the poles of the electro-magnet PP, are separated by about 1 or 2 millimeters, that the wire is a ribbon of bronze about 0.02 to 0.03 millimeter in thickness and 0.10 to 0.20 millimeter breadth and finally that the space between the blades is of the order of 0.1 of a millimeter. Such an instrument would have a period of oscillation of about two or three ten-thousandths of a second.

As has already been said, Belin has never made any but local trials, the line being looped upon the apparatus. Experiments have been made with a line from Paris, through Lyons, Tulle, Bordeaux, Angoulême, and back to Paris, a distance of about 1,717 kilometers. With these conditions and a spacing of about one-sixth of a millimeter between the traces he could reproduce a photograph 13 by 18 centimeters in twenty-two minutes, which, supposing the figure to be composed of points one-sixth of a millimeter on a side, would correspond to 643 signals per second. Belin tried also the transmission of a landscape, which to our knowledge Korn never did; but it seems that he tried to get a transmitted picture in too bold relief and that the spacing of one-sixth of a millimeter is too small, especially if the result is to be used for impressions by the photogravure process. By spacing the traces a little farther apart and augmenting the speed of rotation it would seem possible to obtain beautiful results and a greater velocity of transmission.

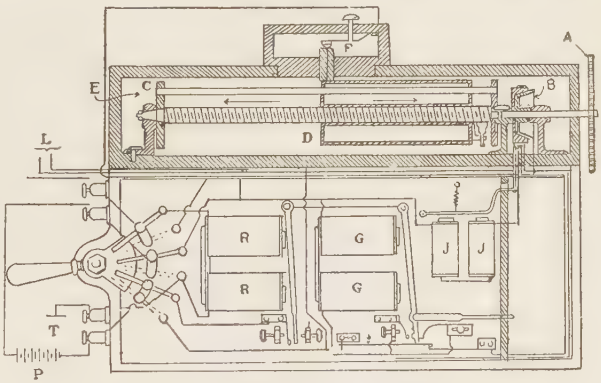


FIG. 8—Berjonneau's apparatus.

APPARATUS OF BERJONNEAU.

Berjonneau used as a transmitter a stereotype plate hatched similar to those used in similigravures. This is rolled upon the cylinder D (fig. 8); all the points of its surface pass under the point of its

style which a spring F presses upon the plate. As this plate is composed of a series of points more and more extended as it is desired to represent a black more and more intense, when the style passes over these points it closes the line through a battery during a greater or less period according to the length of contact touched on the plate and the transmitted signals therefore consist of a series of currents of the same intensity but of varying duration.

A somewhat similar apparatus serves as the receiver. The cylinder D is covered with a sensitive film and before an opening into its dark chamber is placed a lamp. An electro-magnet placed in the line circuit carries a shutter stopping or allowing the light to fall upon the film; the half tones are due to the length of the points traced by the luminous pencil.

APPARATUS OF CARBONELLE.

This system recalls the telegraph of Caselli in its use for the transmitter of a design traced with greasy ink upon a metallic sheet. His receiver, however, is wholly different. It consists of a telephone the membrane of which carries a style which engraves in the wax or lead with which the receiving cylinder is covered. For transmitting photographs or drawings in half tones, Carbonelle suggests the employment of hatched photographs as was done by Berjonneau.

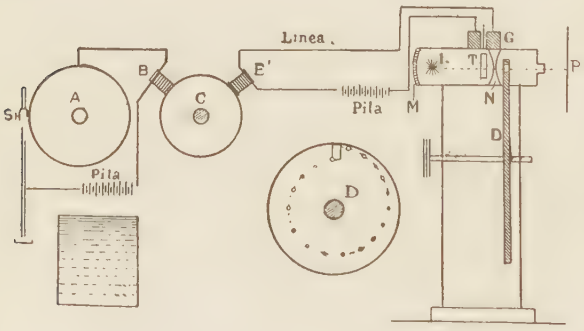


FIG. 9.—Apparatus of Senlecq-Tival.

In the trials between Brussels and Antwerp, Carbonelle sent a picture, 13 by 18 centimeters, in eighty seconds.

APPARATUS OF SENLECQ-TIVAL.

We will say a few words in closing about an apparatus which has been announced but does not appear to have been tried. In the device of Senlecq-Tival, the photograph to be sent is made by the carbon process, using in the place of carbon a conducting powder, and the prepared plate is rolled upon the metallic cylinder A of the transmitter (fig. 9). A style S closes across this film, a circuit consisting of a battery, the electro-magnet B and the cylinder A. Each point of the film has a conductivity proportional to the opacity of

the image; consequently the electro-magnet B receives a current which is a function of this opacity. There is next interposed a device, destined apparently to accelerate the transmission, but whose rôle seems somewhat problematical.

Upon the drum C is wound in a helix a steel wire. Every point of this wire passes consecutively under the electro-magnet B, which produces a magnetism proportional to the intensity of the current. This forms the telegraphone of Poulsen. If now O is caused to turn before another magnet connected with the line, in the line there are produced currents which work a string-galvanometer T, which controls the light striking the sensitive photographic receiving plate.

What is the future of phototelegraphy? At present it would be imprudent to make any prediction. Will a demand be felt for it? Yes, to some extent, especially by the newspapers, which feel a greater and greater need for the rapid transmission of information, oftentimes in the form of photographs or sketches; by the police for the transmission of the description of criminals, etc. But for all these uses evidently the devices must receive many improvements.

On the other hand, is it necessary to wait for the demand before making or improving such apparatus? Evidently it is not, for in that case it would be the organ creating the function. Besides we should recall that these experiments are steps toward seeing at a distance, a problem which does not seem susceptible of direct solution and which, proposed more than thirty years ago, has so far led only to phototelegraphy. The latter may well, however, in its turn, lead us to a solution of the original problem.

THE GRAMOPHONE AND THE MECHANICAL RECORDING AND REPRODUCTION OF MUSICAL SOUNDS.[a]

[With 2 plates.]

By Lovell N. Reddie.

The mechanical recording and reproduction of sounds has already been dealt with in papers read before this society. The talking machine was introduced to the society on May 8, 1878, by Sir William Preece; on the 28th November, 1888, Colonel Gouraud read a paper

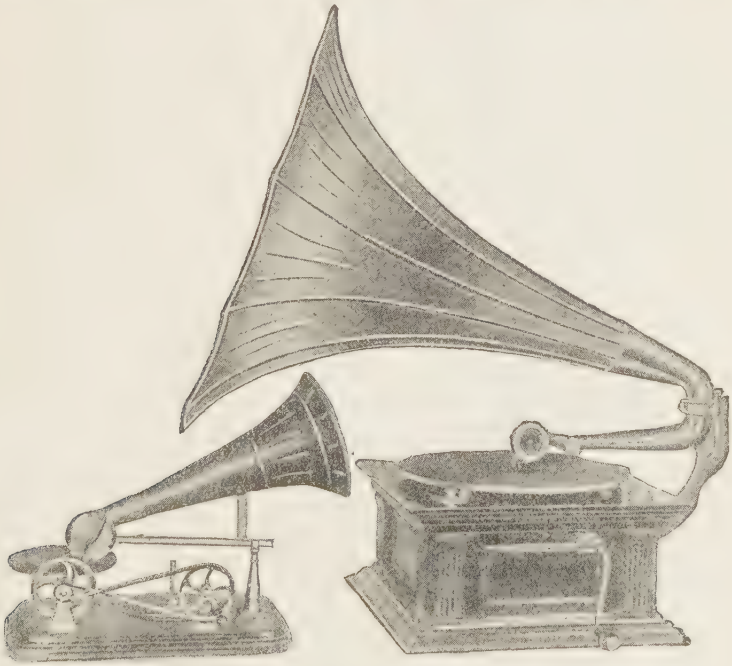


Fig. 1.—Earliest and latest types of gramophone.

entitled "The phonograph;" and on the 5th of December of the same year Mr. Henry Edwards read a paper on "The graphophone." I do not propose this evening to go over the ground covered by these three papers, which deal with the discovery of the talking machine

[a] Reprinted by permission, after revision by the author, from Journal of the Royal Society of Arts, London, No. 2894, Vol. LVI, May 8, 1908, with additional illustrations furnished by Mr. Emile Berliner.

and the improvements made in it up to twenty years ago, but I shall deal more particularly with the invention and the development of a later type of talking machine, and shall describe the various industrial and other processes which are connected to-day with the recording and reproduction of sound by means of this machine.

Before going further I should like to call your attention to two of the instruments before you; the larger machine is one of the latest models of the gramophone and the smaller is one of the earliest types (fig. 1). The difference in appearance of the two machines is striking, but it is small compared with the difference in their capabilities, and, if you will allow me, I will make this apparent by endeavoring to obtain an audible reproduction from the old-fashioned type, and will then play a short selection on the up-to-date instrument.

The progress made toward perfection during the period of twenty years since the invention of the gramophone has been very considerable, and so rapid has it been in recent years that too many people to-day when they hear the word "gramophone" mentioned immediately think of an instrument like this (small machine) and of the sounds which it produced just now. The particular lines upon which improvements have been carried out I will deal with later.

The gramophone was invented by Mr. Emile Berliner. At an early age he left his home in Germany and went to America, where he worked for a number of years with great success on telephone construction. He afterwards turned his attention to the improvement of the talking machine, and on May 4, 1887, just twenty-one years ago, he filed an application for patent in the United States, and a corresponding application in this country in November of the same year. On May 16, 1888, he exhibited his invention before the Franklin Institute, Pennsylvania.

At the date of Mr. Berliner's invention, machines for recording and reproducing sound were already known and in use. Some ten years earlier, in 1878, Mr. Thomas A. Edison had patented the first practical talking machine, and he termed the recording machine, the record, and the reproducing machine a phonograph, a phonogram, and a phonet, respectively. In 1885 the graphophone was invented by Prof. Graham Bell and Mr. C. S. Tainter, of telephone fame, who, working as the Volta Laboratory Association of Washington, had been studying the problem of recording and reproducing sound for some years. The fundamental principles on which these two instruments, the phonograph and graphophone, worked were the same. In each case the sound waves set up in the air by any source of sound were allowed to strike a delicately held diaphragm, which vibrated under the impact of the sound waves. The vibrations of the diaphragm were made to leave a record on a suitable medium, and

this sound record was in turn used to perform the inverse operation when it was required to reproduce the recorded sounds; that is to say, the record was made to vibrate a sensitive diaphragm, and this set up in the air particular waves, which conveyed to the ear of the hearer the impression of sound. The essential difference between the Edison and the Bell and Tainter types of sound recording and reproducing machines lay in the manner in which the vibrations of the diaphragm were recorded, for while Edison's invention consisted in *indenting* a record with an up and down sound line, Bell and Tainter obtained a record by *cutting* an up and down line in a suitable medium. According to both these inventions, therefore, the vibrating diaphragm was made to produce on the surface of the record a sound line of varying depth. Berliner, on the other hand, traced or cut his record in the recording medium in the form of a sinuous line of uniform depth (fig. 2), "substantially," as he says in his patent specification, "in the manner of the phonautograph," invented in 1857 by Léon Scott.

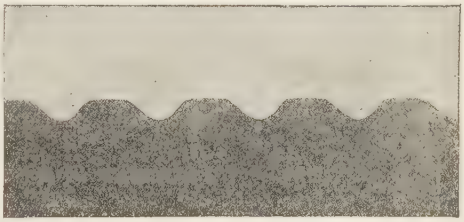


FIG. 2.—Section across sound lines of gramophone record. (Magnified 50 diam.)

The idea of recording and reproducing speech on this system had also occurred to a Mr. Charles Cross, a Frenchman, who on April 30, 1877, deposited a sealed packet with the Académie des Sciences, Paris, in which he disclosed the idea of reproducing sound by means of a permanent metal record obtained from a Scott phonautograph by photoengraving through the coating of lampblack in which the sound line was traced. Thus he anticipated Berliner, and Edison as well, as far as the idea went; but he can not be said to have disclosed the means of carrying his ideas into practice. Mr. Berliner only became aware of this gentleman's invention three months after he had filed his own application for a patent. In the Electrical World of November 12, 1887, in which he first made public his invention of the gramophone, he writes of Mr. Cross as follows:

> Although he had virtually abandoned his invention, the fact remains that to Mr. Charles Cross belongs the honor of having first suggested the idea of and a feasible plan for mechanically reproducing speech once uttered.

The reasons which led Berliner to adopt a different system of recording and reproducing sound from that employed by Edison and the Volta Association are clearly set out in the introduction to his first patent specification, No. 15232, of 1887, where he says:

> By the ordinary method of recording spoken words or other sounds for reproduction, it is attempted to cause a stylus attached to a vibratory diaphragm

to indent a traveling sheet of tinfoil, or other like substance, to a depth varying in accordance with the amplitudes of the sound waves to be recorded. This attempt is necessarily more or less ineffective, for the reason that the force of a diaphragm vibrating under the impact of sound waves is very weak, and that in the act of overcoming the resistance of the tinfoil, or other material, the vibrations of the diaphragm are not only weakened, but are also modified. Thus, while the record contains as many undulations as the sound which produced it, and in the same order of succession, the character of the recorded undulations is more or less different from those of the sounds uttered against the diaphragm. There is, then, a true record of the pitch, but a distorted record of the quality of the sounds obtained.

With a view of overcoming this defect, it has been attempted to engrave, instead of indent, a record of the vibrations of the diaphragm, by employing a stylus, shaped and operated like a chisel, upon a suitably prepared surface; but, even in this case, the disturbing causes above referred to are still present. In addition to this, if in the apparatus of the phonograph or graphophone type, it is attempted to avoid the disturbing influence of the increase of resistance of the record surface, with the depth of the indentation or cut as much as possible, by primarily adjusting the stylus so as to touch the record surface only lightly, then another disturbing influence is brought into existence by the fact that with such adjustment, when the diaphragm moves outwardly, the stylus will leave the record surface entirely, so that part of each vibration will not be recorded at all. This is more particularly the case when loud sounds are recorded, and it manifests itself in the reproduction, which then yields quite unintelligible sounds.

It is the object of my invention to overcome these and other difficulties by recording spoken words or other sounds without perceptible friction between the recording surface and the recording stylus, and by maintaining the unavoidable friction uniform for all vibrations of the diaphragm. The record thus obtained, almost frictionless, I copy in a solid resisting material, by any of the methods hereinafter described; and I employ such copy of the original record for the reproduction of the recorded sounds.

Instead of moving the recording stylus at right angles to, and against the record surface, I cause the same to move under the influence of sound waves parallel with and barely in contact with such surface, which latter is covered with a layer of any material that offers a minimum resistance to the action of the stylus operating to displace the same.

He then proceeds to a detailed description of his instrument, which he terms a "gramophone."

Nowadays the term "phonograph" is popularly applied to a sound-reproducing machine which plays a cylinder record, while "gramophone" is often incorrectly used for any disk machine. This distinction is not, however, correct. It is a fact worth noting that the first figure of the drawings in Berliner's original patent shows a record wound on a cylindrical support, whereas the first figure in Edison's patent shows a disk record, thus directly contradicting the popular distinction just referred to.

According to the specification of his first patent, Mr. Berliner made his sound record as follows: He took a strip of paper, parchment, or metal, A (fig. 3), stretched it round a drum, B, and coated it with

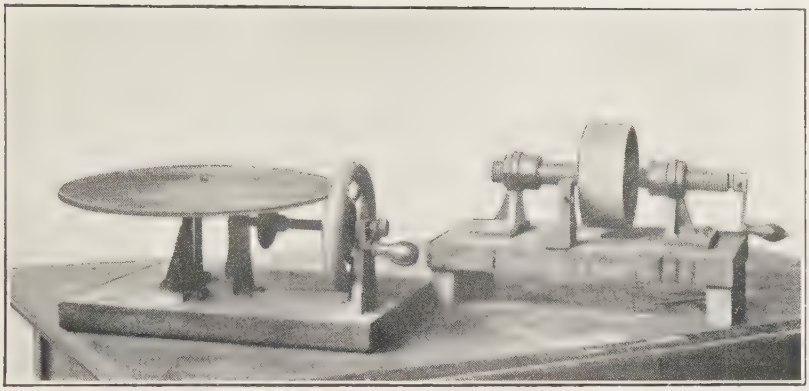


FIG. 1.—APPARATUS, 1887-88.

Cylinder machine on which first gramophone record was made in 1887. Photograph furnished by E. Berliner.

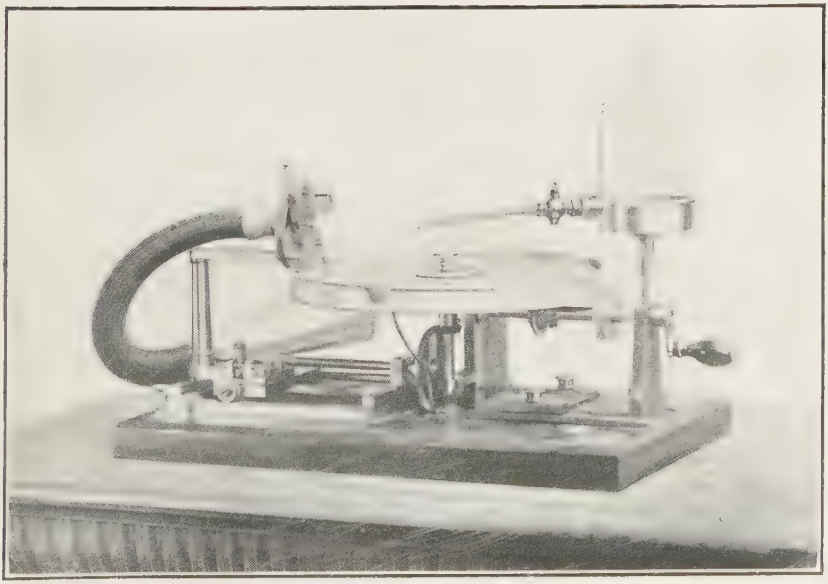


FIG. 2.—RECORDING MACHINE, 1889.

Photograph furnished by E. Berliner.

a layer of lampblack, or other substance which could be easily removed by the point of the stylus. He provided a diaphragm, C, which was held by its edges in a casing, D, and to the center of this diaphragm he attached one end of the recording stylus, E. This stylus or bar was fulcrumed halfway down to the side of the diaphragm casing, and the other end was left free to move in accordance with the vibrations of the diaphragm under the impact of the sound waves. The point of the stylus lightly touched the strip on which the record was to be traced, and as the diaphragm was spoken against, and the drum rotated, the stylus removed the lampblack from the record in a sinuous undulating line. The record thus obtained he proposed to preserve by coating it with varnish or the like. For the purpose of reproduction he copied the record in a resisting material, either mechanically, by engraving, or by etching, or photo-engraving, and this gave him a permanent record, consisting of a wavy grooved line in a strip of copper, nickel, or other material. To reproduce the sounds recorded, this strip was in turn stretched round a drum, the point of the stylus placed in the groove, and the drum rotated. This caused the diaphragm to which the other end of the stylus was attached to vibrate and reproduce the recorded sounds. The specification continues:

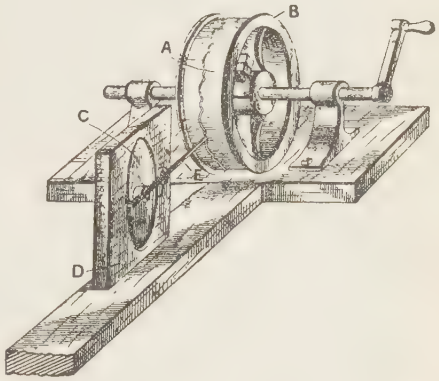


FIG. 3.—Model of first gramophone patent.

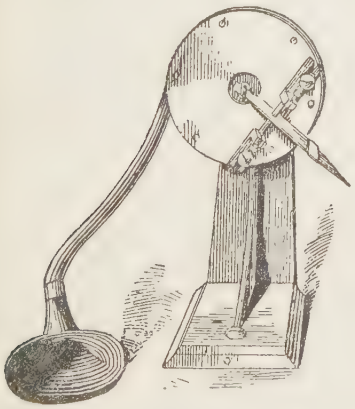


FIG. 4.—Berliner recording diaphragm and stylus (1888). (Cut furnished by E. Berliner.)

> In the phonograph and graphophone the end of the reproducing stylus which bears upon the indented or engraved record, has a vertical upward and downward movement; it is forced upwardly in a positive manner by riding over the elevated portion of the record, but its downward movement is effected solely by the elastic force of the diaphragm, which latter is always under tension. In my improved apparatus the stylus travels in a groove of even depth and is moved positively in both directions; it does not depend upon the elasticity of the diaphragm for its movement in one direction. This I consider to be an advantage, since by this method the whole movement of the diaphragm is positively controlled by the record, and is not affected or modified by the physical

conditions of the diaphragm, which conditions necessarily vary from time to time, and constitute some of the causes of imperfect reproduction of recorded sounds.

It is this feature of the positive control of the diaphragm, coupled with the uniform friction and resistance in the cutting operation, and the consequent accurate tracing of the curve of the sound wave, that has brought the Berliner type of machine to the forefront as a musical instrument. While the cylinder machine with the up and down cut offers advantages for making records at home and for office work, being handier, for instance, than the disk recording machine, it has not been found possible to obtain the same truth of reproduction of musical sounds that can be obtained with the gramophone. An examination of the microscopic undulations in the sound wave, which determine its pitch, loudness, and quality of timbre (some examples of which I shall show you presently), will make this easy to understand.

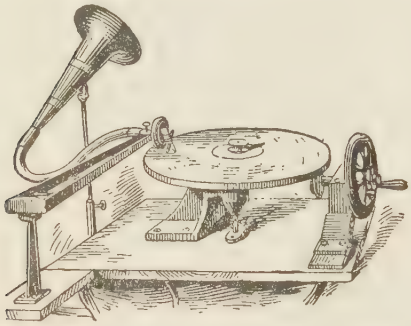


FIG. 5.—Berliner reproducing apparatus (1888). (Cut furnished by E. Berliner.)

In the second or improved form of gramophone described in Berliner's patent, a flat disk record is used, which, he says, offers advantages for copying purposes. Here a disk of glass is employed, and this is covered preferably with a semifluid coating of ink or paint, in which the stylus traces or cuts an undulating line as before. This coating he prefers, because it does not flake and leave a rough-edged line, like the lampblack record. A turntable carries the record disk, and is rotated by any suitable means. As it revolves it is caused to travel slowly sideways past the recording point, so that the sound line takes the form of a sinuous spiral running from the outer edge of the record toward the center, or vice versa. A permanent record in metal is obtained by photo-engraving.

FIG. 6.—Record lines (1888). × 6. (Cut furnished by E. Berliner.

Mr. Berliner's next step was to make a disk record in solid material by direct etching. (United States patent 382790.) To this end he coated a disk or cylinder of zinc or glass with a layer of some substance which, while offering no perceptible mechanical resistance to the movements of the recording stylus, resisted the chemical action of acids. The coating he preferred consisted of beeswax dissolved in benzine. When the recording stylus had traced out its line on the record, and exposed the solid disk below, the latter was etched,

and a permanent record produced. Copies could be obtained by the galvano-plastic process, by making a matrix, and impressing disks of hard rubber or the like. Although this system of etching was considered at the time a great advance in sound recording, it never gave very satisfactory results. Owing to the action of the acid, which, besides biting down into the metal, also undercut the protective coating, the sound line was always left with rough sides, and this roughness was transmitted to the copies, so that the reproduction was accompanied by a very marked and disagreeable scratching sound.

In 1890 the inventor of the gramophone took out patents for further improvements, and in particular for new forms of diaphragm

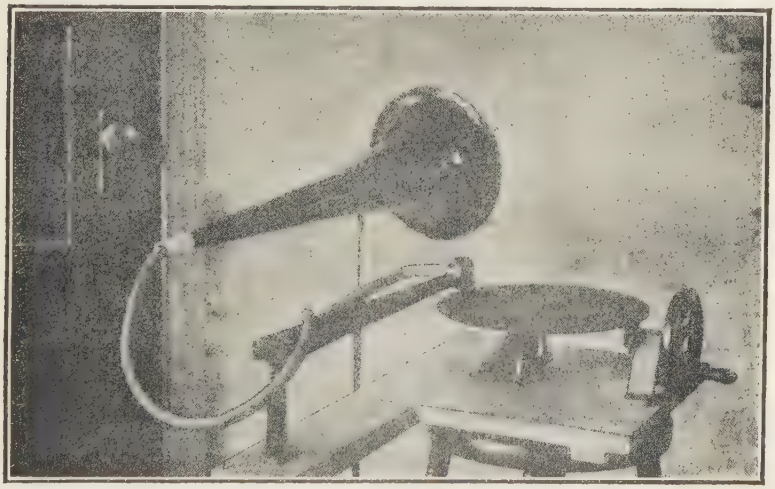


FIG. 7.—Replica of gramophone apparatus used at Franklin Institute, May 16, 1888, the first public exhibition. Now in Deutsches Museum at Munich. (Photograph furnished by E. Berliner.)

holder, or sound box, as it is called, one for recording purposes and the other for reproducing (fig. 8).

Although at this date Mr. Berliner himself had spent much time on improving his invention, the gramophone had not yet become a commercial article. It had not even reached the stage of the small machine you see here. It was looked upon as a scientific curiosity, or at best a toy, but not as a machine which could ever be expected to become an instrument of entertainment, and no one, except, perhaps, the inventor, ever imagined it would attain its present perfection or enjoy its present popularity. The phonograph and graphophone had obtained a firm footing, and for commercial purposes, at any rate, serving, for instance, as automatic stenographers, and in a lesser degree as instruments of entertainment, had attained success.

The Volta people had patented broadly the system of cutting or tracing a sound line in a solid body, so that even Berliner's own method was within the scope of their patent, and from the point of view of patent rights, Mr. Berliner was at a disadvantage. Moreover, the reproduction he obtained was far behind that given by the phonograph and graphophone, for though in the latter instruments the sound waves were distorted, there was a comparative absence of scratch. Very different is the position to-day when in the United States at any rate practically the whole of the enormous trade in disk machines is subject to a Berliner patent No. 534543, which covers the use of a freely swinging sound arm or horn, carrying the sound box and guided throughout the playing of the record entirely by the sound lines.

It was not until the end of 1894 that the manufacture commenced in the United States of a disk record which quickly made the gramophone popular, and may be regarded as the starting point of the industry of to-day. Instead of a record made from an etched metal original, a disk record could now be offered to the public made by a new process which allowed many hundreds of good facsimile copies to be made from one master record. This process consisted in cutting the first record in a disk-shaped blank of wax-like material, obtaining a solid metal negative thereof by electro-deposition, and pressing copies of the original from this negative or matrix in a material which was hard at normal temperatures, but became plastic under heat.

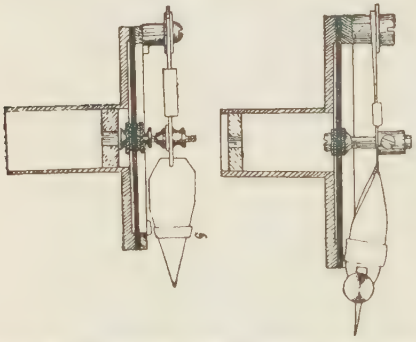


FIG. 8.—Recording and reproducing sound boxes, old type.

About this time a number of inventors began to turn their attention to the improvement of the machine, to keep pace with the vast improvements which were being made in the records. The machine was provided with an efficient governor or speed regulator to insure a uniform speed of rotation of the turntable. Next the hand-driven machine was abolished altogether, and a machine substituted which was driven by a spring motor. To-day the better-class machines are furnished with a motor which will run fifteen minutes or more for one winding of the motor. The speed regulator was furnished with an indicator to show at what speed the machine was running. It will easily be understood how essential it is that the record on reproduction should be revolved at exactly the same pace as the blank on which the original record was cut, if the production is really to be a

true reproduction of the original selection; if, for instance, the record is rotated faster, the sound waves set up by the reproducing diaphragm will be produced at a higher speed than that at which the corresponding sound waves fell upon the recording diaphragm. The greater the frequency of the sound waves the higher the note, so that a record, if played too fast, is pitched in a higher key, and a bass solo can be reproduced in a shrieking soprano.

The sound box went through a series of improvements, the object of the inventors being to render the diaphragm as sensitive as possible either to the sound waves of the selection being recorded or to the vibrations transmitted to it from the record disk, as the case might be. The diaphragm is now lightly held at its edges by hollow rubber gaskets, the fulcrum of the needle connecting the diaphragm to the needle point is formed by knife edges, and its movements are controlled by delicate springs. The standard sound box of to-day is a very different thing from the early patterns shown in figures 1 and 8.

Improvements were further made in the means of conveying the sounds recreated in the sound box to the ear of the auditor. The old ear tubes had disappeared to give place to a small horn, to the narrow end of which the sound box was attached. As the popularity of the gramophone grew, the public wanted more sound for its money, and accordingly the size of the amplifying horn was increased. The increased weight of the horn necessitated that a special bracket should be provided to carry it, and the horn was accordingly balanced with just sufficient weight on the sound-box end to keep the needle well in contact with the record. Thus the machine remained for a time, but in this form it did not satisfy its patrons, for it did not do all that they thought might be expected of it. It was found in practice that the turntable often did not revolve absolutely horizontally, that the record disks were sometimes not absolutely flat, and that the central hole was in reality but seldom accurately in the center of the disk. Owing to the rise and fall of the record as it rotated, the end of the amplifying horn also had to rise and fall, and owing to the eccentricity of the hole in the middle, the sound-box end of the horn was continually approaching and receding from the center of the record, as it followed the sound line. In other words, the needle as it followed its path along the sound groove, in addition to transmitting the proper vibrations to the diaphragm, had also to move the whole mass of the amplifying horn. This had two injurious effects; it impaired the reproduction, and it wore out the record.

The next step was to remove the amplifying horn to a short distance from the sound box and to carry it upon a rigid bracket on the cabinet of the instrument, the sound box being connected to the small end of the horn by a piece of tubing, which allowed the sound box to

move across the turntable and also to be raised or lowered above the record. This arrangement offered the advantage that the weight of the horn was carried by the cabinet, and the record had not to overcome the inertia of the whole horn as before, but only had to move the sound box and its connecting tubing (or sound arm as it is called) when the turntable was not horizontal or the hole in the record not central. But though this arrangement offered advantages in one direction, it was found to be accompanied by imperfection in another. The piece of straight tubing connecting the sound box and the horn had a distorting effect upon the sound waves. Instead of these waves being able to expand uniformly as they advanced, as had been the case in the old arrangement when they passed straight into the horn, they were forced to pass first of all through this straight pipe where the waves became distorted and acoustic interference was created. It was not until 1903 that patents were taken out on an invention which overcame this difficulty (fig. 9), the invention now known as the taper arm, the patent on which in this country was recently upheld in the court of appeal. The inventor had hit upon the idea of jointing the amplifying horn itself, so that while the horn could start immediately next the sound box the latter could be moved with freedom without mov-

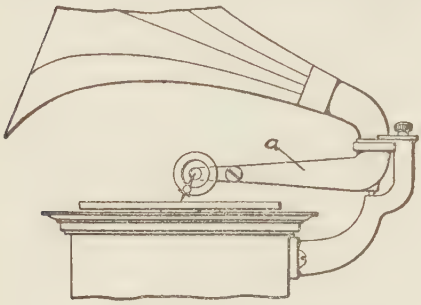


FIG. 9.—Tapering sound arm (*a*).

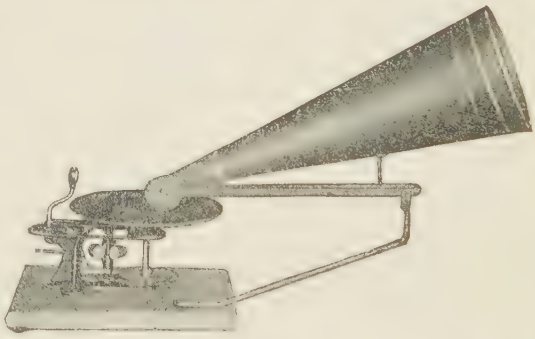


FIG. 10*a*.

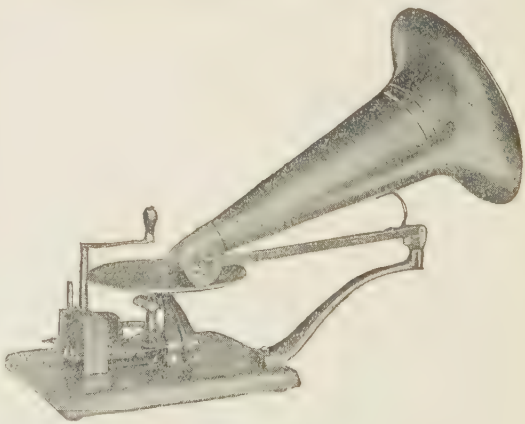


FIG. 10*b*.
Some various stages of development of the gramophone.

ing the heavy bell portion of the amplifying horn. The success of this invention was immediate and pronounced, and a tapering sound arm is now almost a sine qua non.

It was only to be expected that as the reproduction of the machine improved the form in which it was presented to the public would be more and more attractive, and hence the handsome cabinets and pedestals with which the gramophone is furnished to-day.

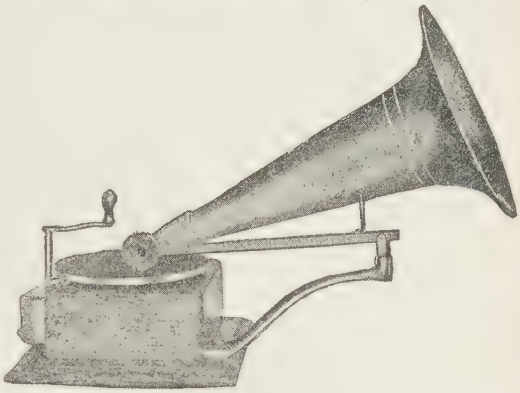


FIG. 10*c*.

Figure 10 shows some of the various stages through which the machine passed. The instrument 10*c* will be recognized as the one before which the dog sat and listened to "his master's voice."

FIG. 10*d*.
Some various stages of development of the gramophone.

An important item in the reproducing apparatus is the needle. Instead of the same blunt point being used over and over again as formerly, a new needle is now recommended for each playing of a record. The reason is that the operation of playing a record wears down the fine point of a needle, so that by the time a record has been played through, the needle point has shoulders worn on it (fig. 11) with only a central projection left to engage in the sound groove; a point of this shape when much worn can not give a good reproduction. The manufacture of gramophone needles constitutes a small industry in itself, and the number of processes through which the needles go before they are ready for use is surprising. Lengths are cut from the best steel wire, and are pointed by emery wheels, rotating about 1,200 times a minute. The needles are cut off, and again the blunt ends are pointed. Some of the machines in use cut off as many

as 200,000 needles daily. The needles are now hardened by tempering, being heated in open pans, almost to white heat, and then suddenly cooled; this is a most important process. They then have to be polished. This is done by packing the needles into bags or sacks and rolling them to and fro for days on a reciprocating table; the constant friction of the needles against one another polishes them bright and smooth.

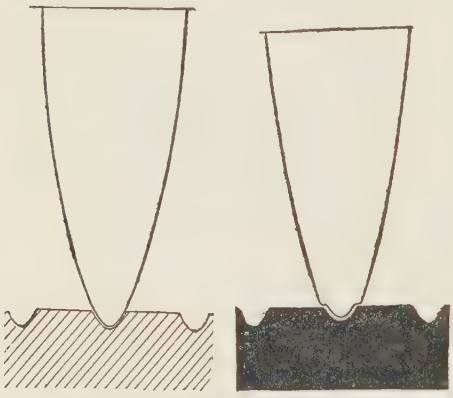


FIG. 11.—Sections of needle point.

I will now deal with the series of operations which go to make a finished disk record of the Berliner or gramophone type. The person who is making the record sings or plays immediately before the mouth of a horn or funnel, the object of the horn being to concentrate the energy of the sound waves upon the recording diaphragm. At the narrow end of the horn is the recording sound box and machine and its attendant expert. The artist is on one side of a screen and the machine on the other, for in all the recording laboratories of talking-machine manufacturers the secrets of the operation of recording are most carefully guarded. I have here a sketch (fig. 12) drawn by a famous singer of himself making a record. The making of a good record is not so simple a matter for the artist as might appear; he often has to make several trials before he learns just how to sing into the trumpet, how near to stand, etc. When singing loud, high notes he must not come too near the mouth of the funnel, as otherwise the vibrations will be too powerful and the result will be what is technically known as "shattering." When the artist is singing or playing to an accompaniment another horn connected with the same sound box is often provided so that the person of the artist may not obstruct the sound waves of the orchestra or other accompaniment.

FIG. 12.—Making a gramophone record.

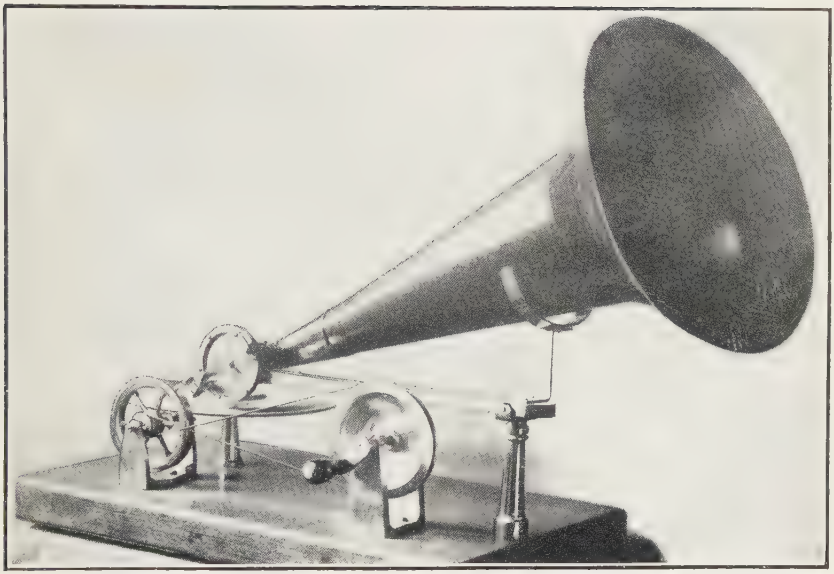


FIG. 1.—1894 GRAMOPHONE.
Photograph furnished by E. Berliner.

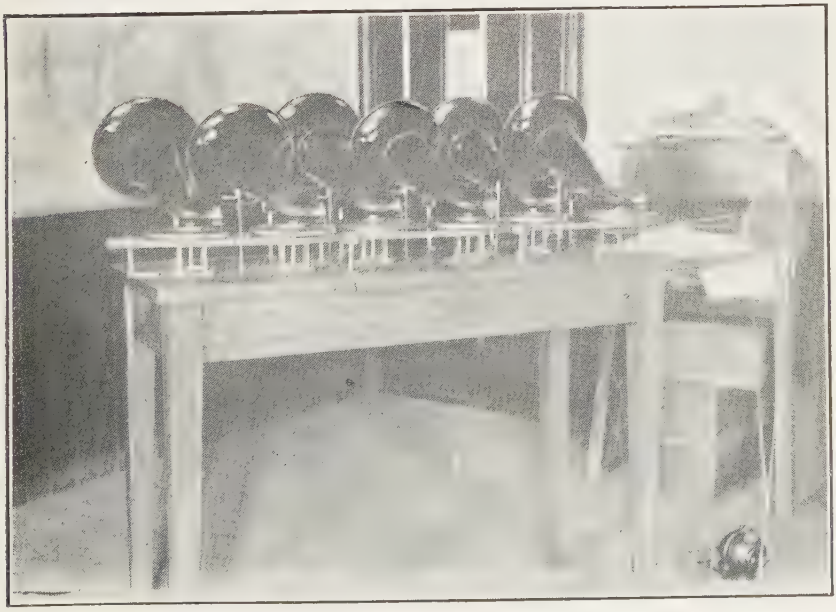


FIG. 2.—MULTIPHONE.
Photograph furnished by E. Berliner.

The disposition, too, of the various instruments of an orchestra in the recording room is of the very highest importance if the best results are to be obtained. The wooden instruments are arranged about 4 feet from the mouth of the trumpet; behind them are the brass instruments, and at the back the bass fiddles and drums.

On the other side of the screen a horizontal table, carrying a wax tablet, is rotated beneath the recording sound box at a fixed and uniform speed, generally about 76 revolutions per minute. As the table rotates it also travels laterally at a fixed and uniform speed, being carried on a revolving threaded spindle, and the wax tablet or blank is thus caused to travel slowly under the stationary recording box. The sapphire cutting point of the sound box is lowered so as to enter the surface of the blank to the depth of about 0.0035 to 0.004 of an inch, and as the machine runs it cuts a fine spiral groove of uniform depth, running from the circumference of the blank to within 2 or 3 inches of the center, according to the length of the selection recorded.

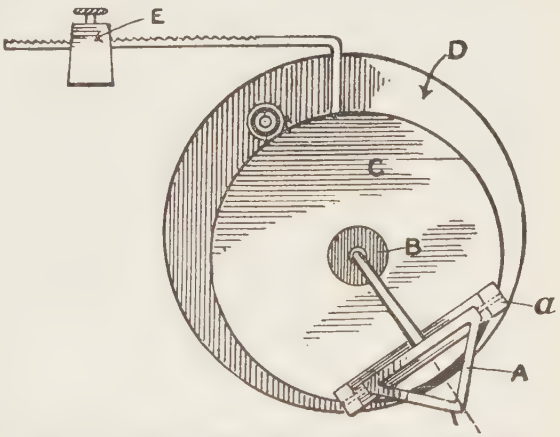


FIG. 13.—Recording sound box. A, stylus; *a*, stylus bearings; B, diaphragm; C, diaphragm holder; D, flange of sound tube; E, counterweight.

The exact construction of sound box used for recording is not disclosed by the experts, but we may take as illustrative two forms which are covered by British patents, Nos. 659–01 and 627–01 (figs. 13 and 14).

The turn table travels, as a rule, about 0.01 of an inch laterally for every revolution, so that the spiral cut comes round about 100 times in the width of 1 inch. It will thus be evident that the lateral undulations of the sound line must be minute in the extreme as otherwise the lines would at points break into one another.

The recording blank is made of a soapy wax. Each laboratory has its own receipt for the composition of the blank, but generally speaking the compound is made up of stearin and paraffin. Many other substances have been suggested, among which may be mentioned barium sulphate, zinc white and stearin, ozokerit and paraffin.

The consistency of the blank material must be such that it is stiff enough to retain its shape when the sound groove is cut in it, and at the same time it must not be so stiff as to offer any great resistance

to the cutting point. It must not chip nor flake, as otherwise the recording point will cut a groove with ragged sides, and this will increase the scratching sound made by the needle on subsequently reproducing. The best results are obtained by a tablet of such consistency that the cutting point detaches an unbroken thread or shaving of wax.

The diameter of the recording blank varies, but the maximum diameter employed is about 12 inches. It will be clear that the size of the record can not be increased beyond certain limits, when it is remembered that the blank is revolved at a uniform speed, and that consequently the outer portion of the blank is running past the recording point at a much higher speed than the inner portion, when this is brought under the recording sound box. Thus, with a 12-inch disk, when the cutter is one-half inch from the edge, it will in 1 revolution describe a line on the record of a length approximately equal to the circumference of a circle of 11 inches diameter—that is to say, 34.5 inches. By the time the recording point has worked in another 3 inches toward the center of the tablet the length of its path over the wax will approximately equal the circumference of a circle of 5 inches diameter, or 15.7 inches. The rate of revolution of the tablet being uniform, the sound line at the edge of the tablet is accordingly being cut at more than twice the speed that it is cut at nearer the center, and the speed at which the recording point can be made to cut the sound groove satisfactorily can only be varied within certain limits. If the diameter of the tablet is increased the outside speed will be too great for proper recording, and if the speed of the turntable is correspondingly decreased the ripples in the sound line near the center will be too close together and cramped. There will be too many vibrations per inch of sound line to allow of proper recording and reproduction. The obvious solution would be, of course, gradually to increase the speed of the turntable as the recording point

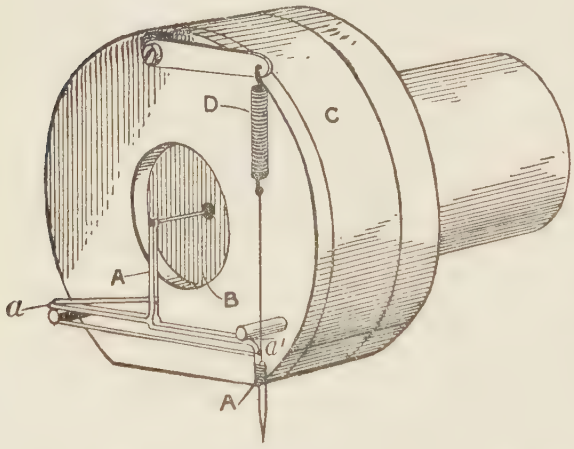


FIG. 14.—Recording sound box. A, stylus; *a*, stylus bearings; B, diaphragm; C, diaphragm holder; D, tension spring.

nears the center of the blank, but there then arises the necessity of using mechanism for securing a corresponding gradual change of speed on the reproducing machine in order to keep the selection in the proper key. Devices for securing an increasing speed have been invented, but they are not free from objection, and have never come into general use.

The record in wax having been made, the next step is to produce a negative in copper. The wax tablet is dusted with graphite, which is worked into the grooves with a badger-hair brush, to make it electro-conductive, and is lowered into the electrolytic bath of copper salt solution. In order that this negative may be able to resist the pressure to which it is subjected in pressing records, it is necessary that the deposition of the copper should be thoroughly homogeneous. To this end, and also in order to hasten the process so that the blank may not be attacked by the solution, the blank is kept continuously in motion in the electrolytic bath. The process is continued until the copper shell is nearly 0.9 of a millimeter in thickness. The negative thus formed may be termed the master negative, and from this master a few commercial samples of the record can be pressed by means of which the quality of the record can be tested. It is not, however, usual to press more than two or three records from this negative. Seeing that sometimes as many as six thousand or more copies are sold of a single record, it is natural that the manufacturers should take steps to enable them to multiply copies without injuring their master negative or having it worn out, for it is not usual at this stage to obtain further negatives from the original wax record. They accordingly make duplicates of their master negative, by taking dubs or impresses of the master in a wax composition, from which in turn working matrices are made. Copper shells are obtained from these dubs in the same way as from the original wax tablet, but the metal is only deposited to the thickness of about half a millimeter. The shells are made absolutely true and flat at the back, so that any irregularities caused in the electro-deposition may not be transferred in pressing to the front or face of the shell. They are then backed up or stiffened by a brass plate about one-tenth of an inch in thickness. The attachment of the backing plate and matrix is effected by sweating or soldering them together under pressure. The backing plate is supported on a heated table, a thin layer of solder is run over it, the shell is laid upon it and pressed firmly down, with an elastic protective cushion of asbestos, for example, placed over the face or recorded surface of the shell to prevent the sound ridges in it from being injured. The matrix thus obtained is now nickel plated on the recorded side so as to present a better wearing surface, and after polishing is ready for use in the pressing machine.

Attempts have been made to use a recording blank of conductive material, or containing sufficient conductive material to allow of omitting the subsequent graphiting or metallising of the blank; the objection to this procedure has always been that such substances offered too much resistance to the recording point.

The commercial record is pressed in a substance the essential qualities of which are that it should be hard at normal temperature, but capable of being softened and made plastic by heat. It must be tough and elastic enough not to be easily broken when pressed into disks of about $2\frac{1}{2}$ mm. in thickness; it must be thoroughly homogeneous; and it must not be gritty in composition, as otherwise it will augment the scratch of the needle, and wear off the point. Finally, the record must be so hard, when cold, that it will retain the contour of the sound groove, even after it has been played a large number of times. Various substances and compounds have been used or suggested for making records; celluloid, glass, papier-maché, vulcanized rubber, casein, and shellac with an admixture of crocus powder. In nearly all the compounds actually used shellac is the principal ingredient.

The compound usually employed to-day is made up of shellac, wood charcoal, heavy spar (barium sulphate), and earthy coloring matter. Various animal and vegetable fibrous materials, such, for instance, as cotton flock, are added to give the record the required toughness. The several ingredients are first finely ground and then carefully measured and mixed according to formula. The mixture is put into a revolving drum, and the flock added. After being passed through a magnetic separator to remove any metallic particles, it is next mixed by heated rollers until a thoroughly homogeneous plastic mass is obtained. The mass is now passed through calendar machines which roll it out into thin sheets, and as it passes from the calendar it is divided into sections, each section being about the requisite quantity for one record.

The records are pressed in hydraulic presses. The matrix is heated and placed face upward in a mold on the lower half of the press, being centered by a pin passing through the middle of it; the label for designating the selection is placed face downward in the matrix, and on this is placed, in a warm, plastic state, the quantity of material required for one record. The press is operated, and the mass is immediately distributed all over the mold. Both halves of the press are furnished with cooling plates, through which a stream of water can be passed so that the pressing surfaces can be immediately cooled, and the record mass consequently hardens quickly and retains the impressions of the matrix. The record is removed, and its edges are trimmed up with emery wheels; for the record material is too hard to allow of any cutting instrument being used. The record is then ready for sale.

It will be seen that the process of producing a commercial record is a long and intricate one. It is, further, a process or series of processes which have required a very high degree of scientific skill and untiring experimental work to bring the sound record to its present pitch of excellence. There are still objections to be overcome, and perhaps the greatest of these is the hissing or scratching sound produced by the needle in reproduction. There is, however, no reason to doubt that eventually this will be overcome. A material will be found for making the records which will insure that the sides and bottom of the sound groove are absolutely smooth. Even this, however, will not entirely eliminate the scratch, which must be regarded to some extent as inherent in the sound groove. The recording point makes a slight hissing noise as it cuts the wax, and that means that the recording point is vibrating on its own account, apart from the vibrations which it is conveying from the diaphragm to the wax tablet; consequently we must expect the recording point to be registering its own scratch vibrations as it goes along. These scratch vibrations are exceedingly minute and of a very high frequency, and in the ordinary course might not be heard were not the diaphragm abnormally sensitive to vibrations of high frequency; the actual result is that the scratch waves are reproduced with proportionately more precision, if anything, than the musical waves of the selection.

An invention has recently been published which, if practicable, should do much to remove the defect of scratch. According to this invention the stylus of the recording sound box, instead of cutting a groove in a wax blank, is made to deposit a fine stream of material upon a polished surface. The original record, therefore, has a raised sound line on it, instead of a grooved one. The substance deposited is one which quickly hardens on deposit, so that it will not spread on the polished surface. A negative is made from this original, and the matrix used for pressing is made from this negative.

Much attention has been bestowed on the diaphragm both of the recording and of the reproducing sound box. Diaphragms have been tried of almost every possible substance. Copper, tin, celluloid, rubber, leather, gold-beater's skin, animal membrane, glass, and mica have all been used, and as many different methods of supporting them in the sound box have also been tried. The object aimed at is to secure a light and highly sensitive diaphragm, and to hold it in the sound box so that in vibrating under the impact of the sound waves it will buckle as little as possible, for the effect of buckling is to slightly distort the sound waves. A glass diaphragm is usually employed in recording sound boxes, one being selected out of a score that may be tried. Reproducing sound boxes are now always made with mica diaphragms.

It is interesting to note that steps are to-day being taken in many countries to form collections of voice records of singers, artists, and other famous personages, and that an important part is played by the talking-machine record in science.

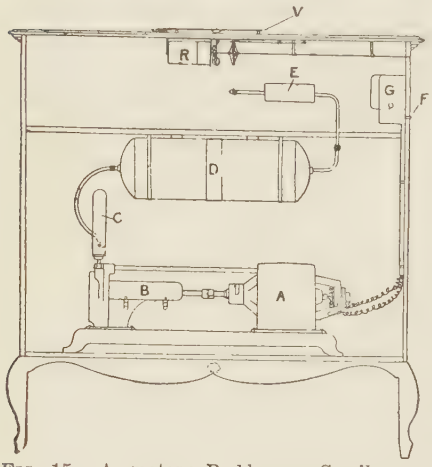


FIG. 15.—A, motor; B, blower; C, oil separator; D, air reservoir; E, dust extractor; F, electric switch; G, fuse box; R, turntable motor; V, turntable.

In June of 1906 a number of matrices were deposited at the British Museum of records made by well-known artists and others. These have been sealed up, and are not to be taken out for fifty years. Thus records of these artists' voices have been secured for practically all time.

On the 24th of December, 1907, there were deposited in a vault of the Paris Opera House disks bearing records of the voices of Tamagno, Caruso, Scotti, Plançon, de Lucia, Patti, Melba, Calvé, and other artists. The statute establishing this collection provides that

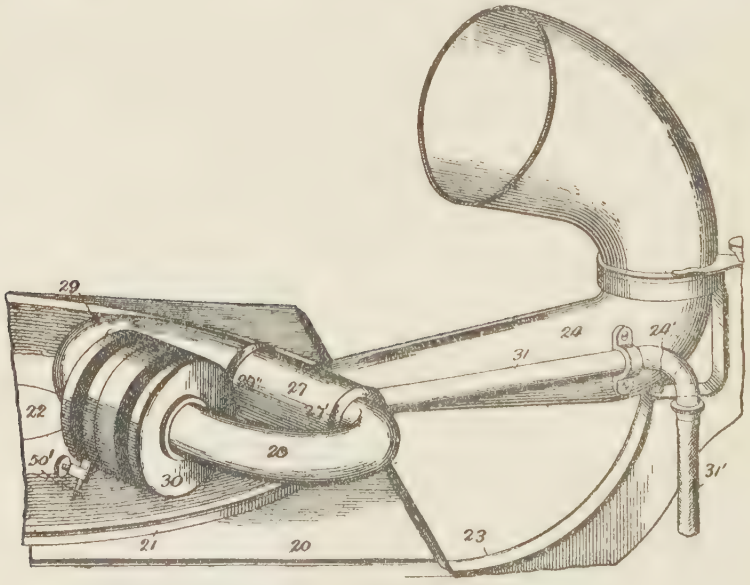


FIG. 16.—Pneumatic sound box and arm in operation.

the records shall be taken out and played once every hundred years. The collection is to be added to every year.

Austria has had a public phonogram record office since 1903. Doctor Pöch, who recently returned from two years wandering among the tribes of South America, brought with him many records of religious, ceremonial, and other songs, which are of great ethnological interest.

In Germany, although no public office has as yet been established, the German Anthropological Society and the Ethnological Museum each have their collections.

A short time ago the Hungarian Ethnological Museum purchased a number of machines, and appointed a certain Dr. Vikar Bela to travel through Hungary and to make records of the various dialects found there, in order that the folk songs of the people might be preserved. The records have been registered and are preserved in the archives of the museum.

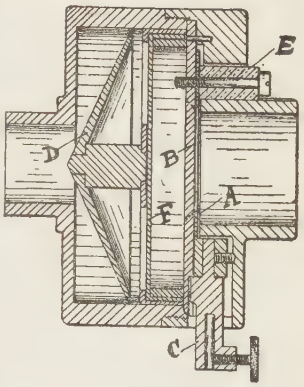


FIG. 17.—Sectional view of pneumatic sound box.

Professor Garner, of the United States, is reported to have taken records of the sounds made by the West African apes, and to be able clearly to distinguish certain sounds betokening, for instance, fear, hunger, friendship. He described how he established himself in a cage in the forest where the apes came and visited him; he held in fact a sort of school which was attended by carefully chosen pupils.

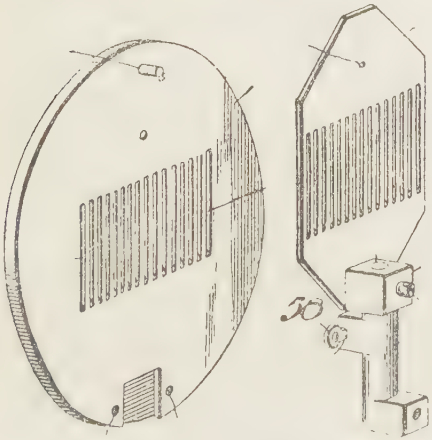


FIG. 18.—Valve of pneumatic sound box.

The story is known of Humboldt finding a parrot in Brazil which was able to speak an otherwise extinct Indian dialect. The scientists of the future will, as you see, have more reliable sources of information in the talking-machine record.

I have here some records made by the Pigmies of Central Africa, who were brought on a visit to this country by Colonel Harrison. If you will permit me I will give you a Pigmy folk song with national accompaniment.

This paper on Mr. Berliner's invention, and the recording and reproduction of musical sounds, would not be complete if I omitted to refer to another instrument, that now known as the Auxeto-Gramophone or Auxetophone, which works on a different principle,

but by means of which sound records of the Berliner type can be most effectively reproduced. In this machine the record does not vibrate a diaphragm, but it vibrates a very finely adjusted valve which controls the flow of a column of air under pressure. As the air passes through the valve there are given to it minute pulsations, which correspond to the undulations in the sound record, so that sound waves identical with those originally recorded are set up in the surrounding air and travel to the ear of the hearer.

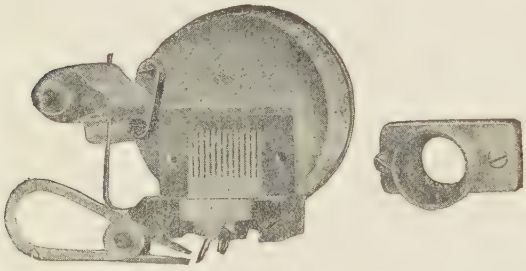


FIG. 19.—Parson's sound box.

In the apparatus you see here (fig. 15), a one-sixth horsepower electric motor drives an air compressor. The air, after passing through an oil separator or filter, enters a reservoir, which helps to insure a regular flow of air to the valve. From the reservoir the air passes through a dust collector before it reaches the valve, as the very fine adjustment of the latter is apt to be interfered with if particles of dust or oil get into it.

The sound box, as you will see on referring to the drawing, comprises a vibrating comb or grid valve, rigidly connected to the stylus bar or needle holder, and a grid valve seat. The valve is on the side of least pressure, and is carried by a spectacle spring (58, fig. 18). The air is deflected to the walls of the sound box by a conical deflector, so that it reaches the whole of the surface of the valve at uniform pressure. A resilient rubber washer holds the grid valve normally against the valve seat. As the needle moves, following the sinuosities of the sound line, the valve moves with it, and thus opens and closes more or less the slots in the valve seat through which the air is rushing. The effect of this I will let you hear for yourselves.

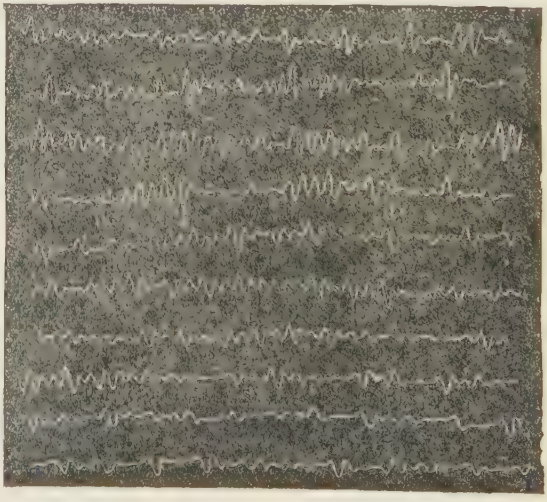


FIG. 20.—Note of orchestra: 0.5 second.

The first practical talking machine working on this principle was made by Mr. Short, who patented his invention in 1898. The Hon. C. A. Parsons then took up the invention, and considerably improved it. I have a model here of the improved Parsons sound box (fig. 19). The auxetophone sound box as used to-day is on substantially the same lines, though its construction has been simplified.

Before closing this paper I should like to give you some details concerning the sound line in a gramophone record, and show you some magnified tracings of sound waves. The approximate length of the spiral line in a fully recorded 12-inch record, carrying the sound line to within $2\frac{1}{4}$ inches of its center, is π times the mean diameter multiplied by the number of turns—that is, $\pi \times 8 \times 350$ inches = 244 yards 1 foot. But this is the length of the line without the ripples. These at least double its length, if the pitch of the record is high and the sounds recorded rich in harmonics, so that we have a sound line over 480 yards long. It is no wonder that the needle point must be finely tempered, and that it shows signs of wear after playing a record. Its average speed over the record is 31.8 inches per second. For a fundamental note on middle C, this gives us about 8 vibrations per inch.

FIG. 21.—Gong: 0.4 second.

FIG. 22.—Piano and whistle: 0.1 second.

FIG. 23.—Plucked string: 0.05 second.

The tracings which I have here are some made by Professor Scripture of Washington, and are reproduced in his interesting work, Researches in Experimental Phonetics. They are traced by a specially constructed instrument from actual gramophone records, and they show the sound line on a very much magnified scale.

The "time equation" of the tracings shown by Professor Scripture is 1 millimeter = 0.0004 second—that is to say, 1 millimeter length of the tracings shows the sound waves produced in 0.0004 of a second, or 8.2 feet per second. The reproductions shown in the figures are about half full size, so that 4.1 feet equals the length of tracing for 1 second.

FIG. 24.—Tremolo: 0.4 second.

Figure 20 shows the waves of a note of an orchestra, produced in just under 0.5 of a second; a vibration with a wave length of about 3 millimeters is noticed occurring again and again. These are seen to be grouped in threes, indicating a tone with a period of 9 millimeters. The presence of loud bass notes is indicated by the greater amplitude of certain waves. There is one which reinforces every sixth vibration; a very complicated curve is the result. It is marvelous that the ear can sift these vibrations so as to distinguish the notes of the various instruments from one another.

Figure 21 shows the vibrations of a gong. The gong is struck, but the special vibrations do not commence immediately. The curve of the low fundamental has other high vibrations traced in it. When the chief tones of the gong interfere they produce beats, as shown in the weak portions.

Figure 22 shows the curve of a whistled note accompanied by piano. The waves of the piano note alone can be distinguished from those where the high whistle vibrations are imposed.

Figure 23 shows the curve of a plucked string.

Figure 24 shows a small portion of a vocal record of an Italian voice on a high note. The rise and fall of the amplitude is noticed, producing a tremolo; the pitch, however, does not rise and fall as it would in a proper trill, which is supposed to be an alternating between two notes. The distinction, however, between the tremolo and trill could not be distinguished by the ear.

Finally, figure 25 shows part of a tracing from the legend of "Cock robin's death and burial." It starts with the fly's response, "With my little eye, I saw him die." Attention may be drawn to the five occurrences of the vowel sound "ai," in "my," "eye," "I," "die," "I." The curves of the two components, the "ah" and the "e" are easily recognized each time they occur. It will be noticed further that the consonants are practically silent and leave an imperceptible record.

That concludes my paper. I have an instrument here which will enable you to see the curve of the actual sound waves of a record being produced by means of a spot of light reflected from a small

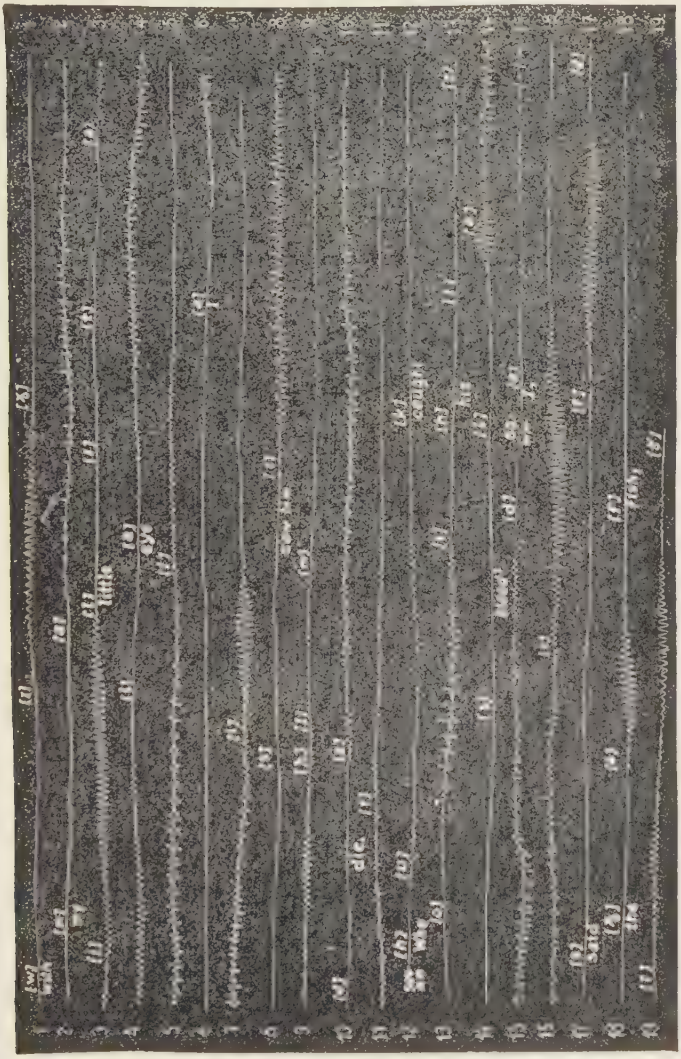


FIG. 25.—Part of "Cock Robin:" 6.5 sec.

mirror attached to a gramophone diaphragm on to a revolving mirror and thence on to a screen. The apparatus is one invented by Mr. G. Bowron.

88292—SM 1908——16

ON THE LIGHT THROWN BY RECENT INVESTIGATIONS ON ELECTRICITY ON THE RELATION BETWEEN MATTER AND ETHER.[a]

By J. J. Thomson, D. Sc., F. R. S.,
Cavendish Professor of Experimental Physics in the University of Cambridge.

When I received the invitation to give the Adamson memorial lecture I felt considerable hesitation about accepting it. I felt there was some incongruity in a lecture founded in memory of a great master of metaphysics being given by one who had no qualifications to speak on that subject. I was reassured, however, when I remembered how wide were Professor Adamson's sympathies with all forms of intellectual activity and how far-reaching is the subject of metaphysics. There is indeed one part of physical science where the problems are very analogous to those dealt with by the metaphysician, for just as it is the object of the latter to find the fewest and simplest conceptions which will cover mental phenomena, so there is one branch of physics which is concerned not so much with the discovery of new phenomena or the commercial application of old ones, as with the discussion of conceptions able to link together phenomena apparently as diverse as those of light and electricity, sound, and mechanics, heat and chemical action. To some men this side of physics is peculiarly attractive; they find in the physical universe with its myriad phenomena and apparent complexity a problem of inexhaustible and irresistible fascination. Their minds chafe under the diversity and complexity they see around them, and they are driven to seek a point of view from which phenomena as diverse as those of light, heat, electricity, and chemical action appear as different manifestations of a few general principles. Regarding the universe as a machine, such men are interested not so much in what it can do as in how it works and how it is made; and when they have succeeded, to their own satisfaction at any rate, in solving even a minute portion of this problem they experience a delight which makes the question "What is the

[a] The Adamson lecture delivered at Victoria University of Manchester, England, November 4, 1907. Manchester University Lectures, No. 8. University Press. 1908. Reprinted by permission of the author and the publications committee of the university.

value of hypothesis?" appear to them as irrelevant as the questions "What is the value of poetry?" "What is the value of music?" "What is the value of philosophy?"

Recent investigations on electricity have done a good deal to unite various branches of physics, and I wish this evening to call your attention to some of the consequences of applying the principle of the equality of action and reaction—Newton's third law of motion—to some of these researches. According to this law the total amount of momentum in any self-contained system, that is, any system uninfluenced by other systems, is constant, so that if any part of such a system gains momentum another part of the system must simultaneously lose an equal amount of momentum. This law, besides being the foundation of our ordinary system of dynamics, is closely connected with our interpretation of the great principle of the conservation of energy, and its failure would deprive that principle of much of its meaning. According to that principle the sum of the kinetic and potential energies of a system is constant; let us consider a moment how we are to estimate the kinetic energy. To us the objects in this room appear at rest, and we should say that their kinetic energy was zero, but to an observer, say on Mars, these objects would not appear to be at rest but moving with a considerable velocity, for they would have the velocity due to the rotation of the earth round its axis and also that due to the revolution of the earth round the sun; thus the estimate of the kinetic energy made by a Martian observer would be very different from our estimate. Now the question arises, Does the principle of the conservation of energy hold with both these estimates of the kinetic energy, or does it depend upon the particular system of axes we use to measure the velocity of the bodies? Well, we can easily show that if the principle of the equality of action and reaction is true, the conservation of energy holds whatever axes we use to measure our velocities, but that if action and reaction are not equal and opposite this principle will only hold when the velocities are measured with reference to a particular set of axes.

The principle of action and reaction is thus one of the foundations of mechanics, and a system in which this principle did not hold would be one whose behavior could not be imitated by any mechanical model. The study of electricity, however, makes us acquainted with cases where the action is apparently not equal to the reaction. Take for example the case of two electrified bodies, A and B, in rapid motion. We can, from the laws of electricity, calculate the forces which they exert on each other, and we find that, except in the case when they are moving with the same speed and in the same direction, the force which A exerts on B is not equal and opposite to that which B exerts on A, so that the momentum of the system formed by B and A does not remain constant. Are we to conclude from this result

that bodies when electrified are not subject to the third law, and that therefore any mechanical explanation of the forces due to such bodies is impossible? This would mean giving up the hope of regarding electrical phenomena as arising from the properties of matter in motion. Fortunately, however, it is not necessary. We can follow a famous precedent and call into existence a new world to supply the deficiencies of the old. We may suppose that connected with A and B there is another system which, though invisible, possesses mass and is therefore able to store up momentum, so that when the momentum of the A and B system alters, the momentum which has been lost by A and has not gone to B has been stored up in the invisible system with which they are in connection, and that A and B plus the invisible system together form a system which obeys the ordinary laws of mechanics and whose momentum is constant. We meet in our ordinary experience cases which are in all respects analogous to the one just considered. Take for example the case of two spheres, A and B, moving about in a tank of water. As A moves it will displace the water around it and produce currents which will wash against B and alter its motion; thus, the moving spheres will appear to exert forces on each other. These forces have been calculated by Kirchhoff and resemble in many respects the forces between moving electric charges; in particular unless the two spheres are moving with the same speed and in the same direction the forces between them are not equal and opposite, so that the momentum of the two spheres is not constant. If, however, instead of confining our attention to the spheres we include the water in which they are moving, we find that the spheres plus the water form a system which obeys the ordinary laws of dynamics and whose momentum is constant; the momentum lost or gained by the spheres is gained or lost by the water. The case is quite parallel to that of the moving electric charges, and we may infer from it that when we have a system whose momentum does not remain constant, the conclusion we should draw is not that Newton's third law fails, but that our system, instead of being isolated as we had supposed, is connected with another system which can store up the momentum lost by the primary, and that the motion of the complete system is in accordance with the ordinary laws of dynamics.

Returning to the case of the electrified bodies we see then that these must be connected with some invisible universe, which we may call the ether, and that this ether must possess mass and be set in motion when the electrified bodies are moved. We are thus surrounded by an invisible universe with which we can get into touch by means of electrified bodies; whether this universe can be set in motion by bodies which are not electrified is a question on which we have as yet no decisive evidence.

Let us for the moment confine ourselves to the case of electrified bodies, the fact that when these move they have to set some of the ether in motion must affect their apparent mass—for exactly the same reason that the apparent mass of a body is greater when it is immersed in water than when it is in a vacuum; when we move the body through the water we have to set in motion, not merely the body itself, but also some of the water around it, in some cases the increase in the apparent mass of the body due to this cause may be much greater than the mass of the body itself. This is the case, for example with air bubbles in water which behave as if their mass were many hundred times the mass of the air inclosed in them. In the case of the electrified bodies we may picture to ourselves that the connection between them and the ether around them is established in the following way, we may suppose that the lines of electric force which proceed from these charged bodies and pass through the ether, grip, as it were, some of the ether and carry it along with them as they move; by means of the laws of electricity we can calculate the mass of ether gripped by these lines in any portion of space through which they pass. The results of this calculation can be expressed in a very simple way. Faraday and Maxwell have taught us to look for the seat of the potential energy of an electrified system in the space around the system and not in the system itself, each portion of space possessing an amount of this energy for which Maxwell has given a very simple expression. Now, it is remarkable, that if we calculate the mass of the ether gripped by the lines of electric force in any part of the space surrounding the charged bodies, we find that it is exactly proportional to the amount of potential energy in that space, and is given by the rule that if this mass were to move with the velocity of light the kinetic energy it would possess would be equal to the electrostatic energy in the portion of space for which we are calculating the mass. Thus, the total mass of the ether gripped by an electrical system is proportional to the electrostatic potential energy of that system. Since the ether is only set in motion by the sideways motion of the lines of force and not by their longitudinal motion, the actual mass of the ether set in motion by the electrified bodies will be somewhat less than that given by the preceding rule, except in the special case when all the lines of force are moving at right angles to their length. The slight correction for this slipping of the lines of force through the ether does not affect the general character of the effect, and in what follows I shall for the sake of brevity take the mass of the ether set in motion by an electrified system to be proportional to the potential energy of that system. The electrified body has thus associated with it an ethereal or astral body, which it has to carry along with it as it moves and which increases its apparent mass. Now, this piece of the unseen universe which the charged body carries along

with it may be expected to have very different properties from ordinary matter; it would of course defy chemical analysis and probably would not be subject to gravitational attraction, it is thus a very interesting problem to see if we can discover any case in which the ethereal mass is an appreciable fraction of the total mass, and to compare the properties of such a body with those of one whose ethereal mass is insignificant. Now in any ordinary electrified system, such as electrified balls or charged Leyden jars the roughest calculation is sufficient to show that the ethereal mass which they possess in virtue of this electrification is absolutely insignificant in comparison with their total mass. Instead, however, of considering bodies of appreciable size let us go to the atoms of which these bodies are composed, and suppose, as seems probable, that these are electrical systems and that the forces they exert are electrical in their origin. Then the heat given out when the atoms of different elements combine will be equal to the diminution of the mutual electrostatic potential energy of the atoms combining, and therefore by what we have said will be a measure of the diminution of the ethereal mass attached to the atoms; on this view the diminution in the ethereal mass will be a mass which moving with the velocity of light possesses an amount of kinetic energy equal to the mechanical equivalent of the heat developed by their chemical combination. As an example, let us take the case of the chemical combination which of all those between ordinary substances is attended by the greatest evolution of heat, that of hydrogen and oxygen. The combination of hydrogen and oxygen to form 1 gram of water evolves 4,000 calories, or 16.8×10^{10} ergs, the mass which moving with the velocity of light, i. e., 3×10^{10} centimeters per second possesses this amount of kinetic energy is 3.7×10^{-10} grams, and this therefore is the diminution in the ethereal mass which takes place when oxygen and hydrogen combine to form 1 gram of water; as this diminution is only about 1 part in three thousand million of the total mass it is almost beyond the reach of experiment, and we conclude that it is not very promising to try to detect this change in any ordinary case of chemical combination. The case of radio-active substances seems more hopeful, for the amount of heat given out by radium in its transformations is enormously greater weight for weight than that given out by the ordinary chemical elements when they combine. Thus, Professor Rutherford estimates that a gram of radium gives out during its life an amount of energy equal to 6.17×10^{10} ergs, if this is derived from the electric potential energy of the radium atoms, the atoms in a gram of radium must possess at least this amount of potential energy, they must therefore have associated with them an ethereal mass of between one-eighth and one-seventh of a milligram, for this mass if moving with the velocity of light would have kinetic energy equal to 6.7×10^{10} ergs. Hence, we con-

clude that in each gram of radium at least one-eighth of a milligram, i. e., about 1 part in 8,000, must be in the ether. Considerations of this nature induced me some time ago to make experiments on radium to see if I could get any evidence of part of its mass being of an abnormal kind. The best test I could think of was to see if the proportion between mass and weight was the same for radium as for ordinary substances. If the part of the mass of radium which is in the ether were without weight then a gram of radium would weigh less than a gram of a substance which had not so large a proportion of its mass in the ether. Now, the proportion between mass and weight can be got very accurately by measuring the time of swing of a pendulum; so I constructed a pendulum whose bob was made of radium, set it swinging in a vacuum and determined its time of vibration, to see if this were the same as that of a pendulum of the same length whose bob is made of brass or iron. Unfortunately radium can not be obtained in large quantities, so that the radium pendulum was very light, and did not therefore go on swinging as long as a heavier pendulum would have done; this made very accurate determinations of the time of swing impossible, but I was able to show that to about 1 part in 3,000 the time of swing of a radium pendulum was the same as that of a pendulum of the same size and shape made of brass or iron. The minimum difference we should expect from theory is 1 part in 8,000, so that this experiment shows that if there is any abnormality in the ratio of the mass to weight for radium it does not much exceed that calculated from the amount of heat given out by the radium during its transformation. With larger pendulums the value of the ratio of mass to weight can be determined with far greater accuracy than 1 part in 8,000; for example, Bessel three-quarters of a century ago showed that this ratio was the same for ivory as for brass to an accuracy of at least 1 part in 100,000; and with apparatus specially designed to test this point an even greater accuracy could be obtained. When I made my experiments with the radium pendulum the close connection between the amounts of uranium and radium in radio-active minerals had not been discovered; this connection makes it exceedingly probable that radium is derived from uranium and that this metal may have weight for weight more electric potential energy, and therefore a larger proportion of its mass in the ether, than radium itself. This points to the conclusion that the proper substance to use for the pendulum experiment is uranium rather than radium, especially since uranium can easily be obtained in sufficiently large quantities to enable us to construct the pendulum of the shape and size which would give the most accurate results, it would not, I think, be impossible to determine the ratio of mass to weight for uranium to an accuracy of 1 part in 250,000.

Though we have not been able to get direct experimental evidence of the existence of the part of the mass in the ether in this way, we are in a more fortunate position in respect to a closely allied phenomenon, viz, the effect of the speed of a body on its apparent mass. We have seen that the mass of the ether bound by any electrical system is proportional to the electric potential energy of that system. Now let us take the simplest electrical system we can find—a charge of electricity concentrated on a small sphere. When the sphere is at rest the lines of electric force are uniformly distributed in all directions round the sphere. When the lines are arranged in this way the electric potential energy is smaller than for any other possible distribution of the lines. Now, let us suppose that the sphere is set in rapid motion, the lines of electric force have a tendency to set themselves at right angles to the direction in which they are moving; they thus tend to leave the front and rear of the sphere and crowd into the middle. The electrical potential energy is increased by this process, and since the mass of the ether bound by the lines of electric force is proportional to this energy, this mass will be greater than when the sphere was at rest. The difference is very small unless the velocity of the spheres approaches the velocity of light, but when it does so the augmentation of mass is very large. Kaufman has succeeded in demonstrating the existence of this effect for the β particles emitted by radium; these are negatively electrified particles projected at high speeds from the radium; the velocity of the fastest is only a few per cent less than the velocity of light; along with these there are others moving much less rapidly. Kaufman determined the masses of the different particles, and found that the greater the speed the greater the mass, the mass of the more rapidly moving particles being as much as three times that of the slower ones. These experiments also led to the very interesting result that the whole of the mass of these particles is due to the charge of electricity they carry. On the view we have been discussing this means that the whole of the mass of these particles is due to the ether gripped by their lines of force.

If lines of electric force grip the ether, then, since waves of light, according to the electromagnetic theory of light, are waves of electric force traveling at the rate of 180,000 miles per second, and as the lines of electric force carry with them some of the ether, a wave of light will be accompanied by the motion of a portion of the ether in the direction in which the light is traveling. The amount of this mass can be easily calculated by the rule that it would possess, if traveling with the velocity of light, an amount of kinetic energy equal to the electrostatic potential energy in the light; as the electrostatic energy is one-half the energy in the light wave, it follows that the mass of the moving ether per unit volume is equal to the energy

of the light in that volume divided by the square of the velocity of light. Thus, when a body is radiating a portion of the mass of the ether gripped by the body is carried out by the radiation. This mass is, in general, exceedingly small. For example, we find by the application of the rule we have just given that the mass emitted by each square centimeter of surface of a body at the temperature of the sun is only about 1 milligram per year. We should expect that when some of the ether, bound to a body by its lines of force, is carried off by the radiation, other portions of ether which will not be connected with the body will flow in to take its place. Thus, in consequence of the radiation which proceeds from all bodies, the ether around them will be set in motion in much the same way as if a series of sources and sinks were distributed throughout the bodies.

Though the actual mass of the ether traveling with a wave of light is exceedingly small, yet its velocity is so great, being that of light, that even a very small mass possesses an appreciable amount of momentum. When the light is absorbed in its passage through a medium which is not perfectly transparent this momentum will also be absorbed and will be communicated to the medium, and will tend to make it move in the direction in which the light is traveling; the light will thus appear to exert a pressure on the medium; the pressure, which is called the pressure of radiation, has been detected and measured by Lebedew, Nicols and Hull, and Poynting. All the phenomena associated with this pressure may be explained very simply by the view that light possesses momentum in the direction in which it is traveling. The possession of momentum by light, supposing light to be an electric phenomenon, has been deduced by somewhat abstruse consideration. On the old Newtonian emission theory it is obvious at once that this momentum must exist, for it is just the momentum of the particles which constitute the light. It is remarkable how recent investigations have shown that many of the properties of light which might be supposed to be peculiar to a process similar to that contemplated on the emission theory would also be possessed by the light if it were an electric phenomenon. There is one consequence of the emission theory to which I should like briefly to allude, because I think it is more in accordance with the actual properties of light than the view to which we should be led if we took the electro-magnetic theory in the form in which it is usually presented. The active agents on the emission theory are discrete particles, a ray of light consisting of a swarm of such particles, the volume occupied by these particles being only a very small fraction of the volume through which they are distributed. The front of a wave of light would on this view consist of a multitude of small bright specks spread over a dark ground; the wave front in fact is porous and has a structure. Now on the electric theory

of light as usually given, it is tacitly assumed that the electric force is everywhere uniform over the wave front, that there are no vacant spaces, and that the front has no structure. This is no necessary part of the electric theory, and I think there is evidence that the wave front does in reality much more closely resemble a number of bright specks on a dark ground than a uniformly illuminated area. Let me mention one such piece of evidence. If a flash of light, especially ultra-violet light, fall on a metal surface, negatively electrified corpuscles are emitted from the surface; but when we measure, as we can do, the number of these, we find that only a most insignificant fraction of the number of molecules passed over by the wave front have emitted these corpuscles. If the wave front were continuous, then all the molecules of the metal exposed to the light would be under the same condition, and although, like the molecules of a gas, the molecules might possess very different amounts of kinetic energy, this difference would be nothing like sufficient to account for the enormous discrepancy between the number of molecules struck by the light and those which emit corpuscles. This discrepancy would, however, easily be understood if we suppose that the wave front is not continuous but full of holes, so that only a small number of molecules come under the influence of the electric force in the light. We may suppose that light consists of small transverse pulses and waves traveling along discrete lines of electric force, disseminated throughout the ether, and that the diminution in the intensity of the light as it travels outward from a source is due not so much to the enfeeblement of the individual pulses as to their wider separation from each other, just as on the emission theory the energy of the individual particles does not decrease as the light spreads out; the diminution of the intensity of the light is produced by the spreading out of the particles.

The idea that bodies are connected by lines of electric force with invisible masses of ether has an important bearing on our views as to the origin of force and the nature of potential energy. In the ordinary methods of dynamics a system is regarded as possessing kinetic energy which depends solely upon the velocities of the various parts of which it is composed, and potential energy depending on the relative position of its parts. The potential energy may be of various kinds; thus we may have potential energy due to gravity and potential energy due to stretched springs, or electrified systems, and we have rules by which we can calculate the value of these potential energies corresponding to any position of the system. When we know the value of the potential energy the method known as that of "Lagrange's equations" enables us to determine the behavior of the system. As a means of calculation and investigation this use of the

potential energy works admirably, and is very unlikely to be superseded; but, regarded from a philosophical point of view, the conception of potential energy is much less satisfactory and stands on quite a different footing from that of kinetic energy. When we recognize energy as kinetic we feel that we know a great deal about it; when we describe energy as potential we feel that we know very little about it, and though it may be objected that from a practical point of view that little is all that is worth knowing, the answer does not satisfy an inquisitive thing like the human mind.

Let us consider a commercial analogy and compare kinetic energy to money in actual cash and potential energy to money at our credit in a bank, and suppose such a state of things to exist that when a man lost a sovereign from his pocket it was invariably collected, he did not know how, and placed to his credit in a bank situated he knew not where, from which it could always be recovered without loss or gain. Though the knowledge that this was so might be sufficient for all commercial purposes, yet one could hardly suppose that even the most utilitarian and matter-of-fact of men could refrain from speculating as to where his money was when it was not in his pocket, and endeavoring to penetrate the mystery which envelops the transfer of the sovereign backward and forward. Well, so it is with the physicist and the conception of different forms of potential energy; he feels that these conceptions are not simple, and he asks himself the question whether it is necessary to suppose that these forms of energy are all different; may not all energy be of one kind—kinetic? and may not the transformation of kinetic energy into the different kinds of potential energy merely be the transfer of kinetic energy from a part of the system which affects our senses to another which does not, so that what we call potential energy is really the kinetic energy of parts of the ether which are in kinematical connection with the material system? Let me illustrate this by a simple example. Suppose I take a body, A, and project it in a region where it is not acted on by any force. A will move uniformly in a straight line. Suppose, now, I fasten another body, B, to it by a rigid connection, and again project it. A will not now move in a straight line, nor will its velocity be uniform; it may, on the contrary, describe a great variety of curves, circles, trochoids, and so on, the curves depending on the mass and velocity of B when A was projected. Now, if B and its connection with A were invisible so that all we could observe was the motion of A, we should ascribe the deviation of A's path from a straight line to the action of a force, and the changes in its kinetic energy to changes in the potential energy of A as it moved from place to place. This method is, however, the result of our regarding A as the sole member of the system under observation, whereas A is in reality only a part of a larger system; when we consider the sys-

tem as a whole we see that it behaves as if it were free from the action of external forces and that its kinetic energy remains constant; what on our restricted view we regarded as the potential energy of A is seen on the more general view to be the kinetic energy of the system B. It is now many years ago since I showed that the effects of force and the existence of potential energy may be regarded as due to the connection of the primary system with secondary systems, the kinetic energy of these systems being the potential energy of the primary, the complete system having no energy other than the kinetic energy of its constituents; a similar view is the foundation of Hertz's system of mechanics.

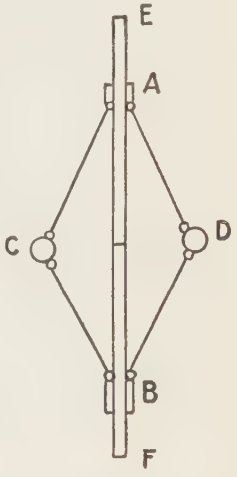


FIG. 1.

Let us consider one or two simple mechanical systems in which the motion of matter attached to the system produces the same effect as a force. Suppose A and B (fig. 1) are two bodies attached to tubes which can slide vertically up and down the rod E F, and that two balls C and D are attached to A and B by rods hinged at A and B, then if the balls rotate about the rod they will tend to fly apart, and as the balls move farther from the rod their points of attachment A and B must approach each other; thus A and B will tend to move toward each other, i. e., they will behave as if there were an attractive force acting between; the velocities of A and B, and therefore their kinetic energy, will change from time to time; the kinetic energy lost by A and B will really have gone to increase the kinetic energy of the balls. If the rotating system C and D had been invisible we should have explained the behavior of the system by assuming an attractive force with corresponding potential energy between A and B. This is due to our considering A and B as a complete system, whereas it is in reality part of a larger system, and when we consider the complete system we see that it behaves as if it were acted on by no forces and possessed no energy other than kinetic.

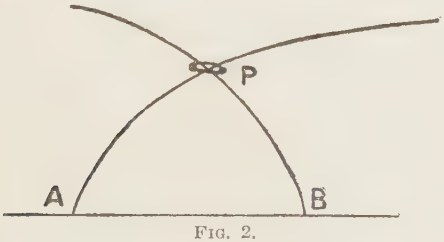


FIG. 2.

It may perhaps be of interest to note that we can in a similar way make two bodies appear to attract each other with a force varying inversely as the square of the distance between them. Let A and B (fig. 2) be the bodies, and suppose that parabolic wires without mass

are fixed to them, if these are threaded through a ring P with a small but finite mass and the system caused to rotate round A and B, the effort of the ring to get away from the axis of rotation will cause A and B to approach each other, and the law of approach may easily be shown to be the same as if there was a force between them varying inversely as the square of the distance.

The result mentioned on page 236 that the potential energy of a system charged with electricity is equal to the kinetic energy of the mass of ether bound to the system when moving with the velocity of light is another example of potential energy, being in reality the kinetic energy of an associated system, and indeed, as I have endeavored to bring before you this evening, the study of the problems brought before us by recent investigations leads us to the conclusion that ordinary material systems must be connected with invisible systems which possess mass whenever the material systems contain electrical charges. If we regard all matter as satisfying the condition we are led to the conclusion that the invisible universe—the ether—is to a large extent the workshop of the material universe, and that the phenomena of nature as we see them are fabrics woven in the looms of this unseen universe.

DEVELOPMENT OF GENERAL AND PHYSICAL CHEMISTRY DURING THE LAST FORTY YEARS.[a]

By W. Nernst.

Although in principle physics and chemistry follow the same methods and look toward a common end, an end which, as Helmholtz has so aptly described it for physics, is "To assert by the logical forms of laws our intellectual mastery over nature, at first a stranger to us," nevertheless the diversity of the problems and facilities has in practice necessitated a separation of the two branches. Consequently the energies of the physicist and chemist have been expended almost entirely on special problems in their own fields of research, and as a result a large boundary region between the two sciences remained neglected for a long time. Only in the period of time which this sketch covers has there been any lively interest in physical and theoretical chemistry.

No one will deny that, as far as any theoretical mastery of matter is concerned, physics has not for a long time made nor is even now making any advances. Why this can not be otherwise is easy to understand. The physicist often needs relatively only a very small amount of material to work on to derive immediately the fundamental theoretical laws of the subject which he is investigating. For example, it is only necessary to know the density of atmospheric air at a single temperature and a single pressure to develop physico-mathematically by the sole aid of the gas laws and the principles of the theory of heat the rule of sound vibration, and from that the fundamental principles of acoustics generally. How different and how much more difficult are the problems which confront the chemist when he attacks the study of atmospheric air, whether he attempts to determine its composition down to the last particle or whether he investigates the remarkable and complex equilibria which obtain at high temperatures.

Chemistry to-day can boast of a set of theoretical principles that do not suffer in comparison with those of physics. What a mass of

[a] Address before the German Chemical Society at the celebration of the fortieth anniversary of the society, November 11, 1907. Translated, by permission, from Berichten der Deutschen Chemischen Gesellschaft, Jahrgang XXXX, Heft 17. Berlin, 1907, pp. 4617–4626.

experimental material is set forth in the table of atomic weights. What quantitative facts can the man of science draw forth from its figures, such as composition, specific heat, vapor density, lowering of the freezing point, and the like of innumerable substances. What can he not forecast, by the aid of general analogy, in the way of physical and chemical properties of many other kinds when he calls to his aid that happy artifice, the periodic classification. The very fact that such an abundance of material has been brought together necessarily increases many times its importance after it has once been successfully classified.

The theory of the constitution of organic combinations furnishes a good example of this fact. In a short time, when the organic compounds gathered together in the new edition of Beilstein's handbook which this society has under preparation are published, we shall, I have been told by the editor, be confronted by more than a hundred thousand structural formulæ. It is by the aid of this theory of organic constitution that a great part of these combinations have been worked out, and it is only by its aid that it has been possible to describe and classify this stupendous amount of material. And if one finally considers all the information the initiated can read out of the structural formulas and considers the mass of experimental data that often had to be obtained to establish even one of them, he realizes that in the quantity of experimental facts logically construed and classified, the doctrine of the constitution of organic combinations stands at the head of all theories that the human mind has conceived.

Another effect of the development of chemistry from the theoretical point of view is that already in a great many cases theoretical and experimental work can hardly be distinguished, so impregnated with theory have most of the branches of chemistry become. Consequently, it is my task to-day to give not a general view of the whole of theoretical chemistry, but merely of that part which may be called physical.

In the first part of this sketch the relations between physical properties and chemical constitution will be touched on, a subject which formed the principal field of research for physico-chemical work in the latter half of the period we are considering. The description of this work will be very much facilitated by an adherence to a systematic mode of classification, according to which the properties of substances are divided into three groups.

There is, first, the measurement of those accessible quantities which render possible the immediate deduction of the values for the molecular weights, and which may be briefly designated as molar properties. Among these, as Avogadro has shown, the vapor density deserves a

place in the first rank, but it has been left for the new epoch, by the aid of the direct and indirect methods of measuring osmotic pressure, to throw an equal light on the molecular weight of dissolved substances. In the determination of the molecular weight of liquids the value of the temperature coefficient of surface tension has been of the greatest assistance; the heat of vaporization, the critical constants, the curves of vapor tension, and a series of other values, also furnish more or less sure means to the same end.

All these methods, with complete accord, lead to the conclusion that most substances, for instance the saturated hydrocarbons, possess the same molecular weight in the liquid state as in the gaseous condition, but that a number of substances, like the alcohols and especially water, are more or less highly polymerized in the liquid condition. But what is the degree of polymerization in each particular case? What equilibrium is established in these pure liquids? These interesting questions unfortunately still evade any exact or quantitative solution.

As the most important results of these new methods of determining molecular weights, especially of the osmotic method, we may mention first the ingenious theory of the existence of colloidal solutions as an intermediate stage between true solutions and mechanical suspensions, and then the more definite conception of the ion to which we shall return later.

A second series of properties are those designated under the name of additive properties. Any such property of a combination is the resultant sum of the properties of its constituents. To all appearances this is a very simple rule, but at the same time it is impossible to form any idea from it as to the size and structure of the molecule. Among these properties we may note, beside the molecular volumes of liquid organic compounds, molecular refraction, magnetic rotation, heat of combustion and the critical coefficient.

A third series of properties depends not only on the nature of the atoms which exist in the molecule, but also on their arrangement in the molecular structure; accordingly they are designated constitutive properties. Thus the molecular refraction of hydrocarbons depends not only on the number of hydrogen and carbon atoms present, but also on the existence or nonexistence of multiple bonds between the carbon atoms.

From this we derive a very important result; we may attribute to the double bond a determinate amount of refraction and take into account with a high degree of approximation, the influence of its constitution, by a return to the additive method.

Frequently certain properties appear only with a particular grouping of atoms. In such case it is a qualitative rule of the highest

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value that, inversely, from the appearance of these properties we can predicate the existence of these definite forms of combination. The classic example of this type is afforded by the power of optical rotation in carbon compounds, which is dependent on the existence of one or more asymmetric carbon atoms (or similar asymmetric structures) in the molecule.

In the same way in these organic compounds one can discover from the appearance of color, or more exactly, from the appearance of certain characteristic absorption bands, as well as of fluorescence the existence of particular groupings in the molecule. To this same category of properties belongs also, in the largest sense, electrolytic conductivity, which indicates the existence of free ions—that is to say, the combination of elements or radicles with electrons: and lastly, the appearance of the maximum value of 5:3 for the ratio of the specific heats of a gas is, according to the kinetic theory of gases, an indication of a monoatomic state, a conclusion which, as is generally known, was first applied to mercury vapor, and which in recent times has been of inestimable service in the determination of the atomic weights of the argon group of elements.

In the last analysis all these properties are probably constitutive also, and their interpretation as either purely molar or purely additive is only a more or less close approximation. Often, even in the regions which have already been cleared up to a great extent by the additive method, great difficulties have appeared upon a more careful investigation. I should like, therefore, all the more to place before you a special case where the theory seems to have reached the greatest exactitude.

We have succeeded in reducing to exact terms the gas densities which for a long time afforded the only means of molecular weight determination. On account of the variation from the laws of perfect gases, which all actual gases show, it was natural that a method of approximation should be developed. In our epoch, however, we have learned with the help of van der Waals' equation, particularly by using compressibility, to reduce all gases to the ideal gaseous state and thence to deduce the exact relative values of molecular weights.

From these results, two ends have been attained: First, it has been proved that the most important of the theoretical laws that we possess, Avogadro's rule, appears to be an infinitely exact natural law; and second, a new method, purely physical, of determining atomic weights has been acquired which can stand comparison in exactness with the methods of analytical chemistry, but which is limited naturally to the cases where the density and compressibility of a chemically pure gas can be determined.

The problem, however, of reconciling experience and theory in the case of some other physical properties, as successfully as in this example, seems still far from solution. In general the exactness and consequently the reliability of theoretical treatment have been more striking in connection with the theory of corresponding states which we shall now take up.

In the theoretical consideration of natural processes, it has generally been considered necessary to take account only of very small variations of the system under observation; a variation of any extent caused so many complex accessory phenomena that it was impossible for the mind's eye to follow them. Thus in theoretical physics we see the quintessence of nearly all theories represented by a differential equation, that is to say, by a mathematical formula which has to do with only infinitely small variations. The establishment of a differential equation (assuming, of course, that it can be solved) has a symtomatic signification in a science, since its employment proves that the region of corresponding phenomena has been carefully considered. It was, however, by a rare and fortunate chance that the law of mass action was established in chemistry some forty years ago.

I recall very vividly the great surprise I experienced when for the first time a differential equation appeared to me in the study of the speed of reaction of the saponification of ethers, especially when I discovered how beautifully the integral of this equation was confirmed by the facts. How many inconsistencies, how many irregularities, and how many values depending on all sorts of conditions appear at first glance in chemical phenomena! Nevertheless the law of mass action shows us that, if we disregard the secondary phenomena of supersaturation and the like, if we maintain a constant temperature, and if we consider a chemically homogeneous system, we will have to deal with phenomena very clearly defined and calculable with mathematical precision.

The law of mass action furnishes at the same time the law for static and kinetic chemistry. It gives us the outlines not only for the experimental investigation of chemical equilibrium but for the speed of chemical reaction. Therefore I can cite as the most important result of the last forty years in this field the fact that not only are we in possession of the laws of chemical equilibrium and the speed of reaction, but above all we can classify a great many experimental facts as logically following the law of mass action. This law, as I have stated, is of the most general application, but experience shows us that general theories are not very profitable. Accurate results are never obtained except by fortunate specialization.

Organic chemistry, characterized by the inertia of the bonding of the carbon atom, furnishes a vast field for the application of kinetic chemistry, while the solutions of salts, acids, and bases which are

characterized by the practically instantaneous nature of a certain category of chemical reactions offer an almost inexhaustible series of chemical equilibria.

Here, however, the law of electrolytic dissociation comes to our aid, a law derived, it is true, in principle from experiments on the electric conductibility of dilute saline solutions, but which was first put on a reliable experimental footing by the osmotic method of molecular weight determination.

The importance of this doctrine extends far beyond the field of chemistry proper. Briefly described, its application to chemical processes consists in the fact that it allows an exact application of the laws of static chemistry to characteristic aqueous solutions and through these to the reactions of ordinary analytic chemistry.

The later refinement of this doctrine has resulted in a very detailed theory of equilibrium in dilute solutions, and in particular in the proof of the fact that when, for a certain solvent, the coefficients of dissociation and solubility of those electrically neutral molecules which are composed of several combined ions are known, the equilibrium in this solvent can be calculated, and if the coefficients of distribution are known, the equilibrium in any other solvent whatever can be derived with equal facility.

On account of the simplicity of the gaseous state we should expect that the law of mass action would be particularly profitable in reference to this phase. But it was found that at low temperatures the speeds of reactions, like many of the reactions of organic chemistry, were generally very small. At high temperatures, however, equilibrium was established as in ionic reactions almost instantaneously. But in this simple field there are, at the lower temperatures, difficultly controlled catalytic influences, and at the high temperatures inherent experimental difficulties place themselves in the way. It is nevertheless to be hoped that in this field of gaseous reactions which investigators are now eagerly attacking from different points, a wealth of material and a corresponding theoretical profit will soon be forthcoming.

In the application of thermodynamics to chemical phenomena lies another field where the methods of theoretical physics have been fruitful. There, too, the first great step in advance was taken almost forty years ago. The work I allude to is that particularly important proof that the chemical law of mass action should be recognized as a direct application of thermodynamics, which is found in volume 2 of the transactions of the German Chemical Society.

Among the further results obtained in this way I should state that the aid of thermodynamics alone has made possible the close and exhaustive study of heterogeneous equilibria, particularly those where mixtures of given concentration (not only dilute solutions) enter into

the equilibrium. For special cases of heterogeneous equilibria there comes into play the so-called "phase rule," which expresses in principle that in every case fixed (stable) equilibria correspond to given conditions of temperature, pressure, and concentration. This rule is therefore rather a reliable formula than a theory proper, and that is why from many sides we are warned not to exaggerate its value. More important from a theoretical standpoint is the demonstration in chemical compounds of two sorts of stability. One is the apparent stability which is characterized by the fact that its speed of decomposition is very slow (examples: Nitric oxide, hydrogen peroxide, and most organic compounds), and the other, the true stability, which is characterized by the fact that the equilibrium depends on a quantitative formation of the substance considered apart from its components.

Electrochemistry and photochemistry are governed by laws closely related to those of thermochemistry. Although the study of the latter of these two fields has presented, up to the present time, great difficulties in the way of theoretical investigation, Faraday's law, which establishes the proportion between chemical transformation and the quantity of electricity passed through a system in a given time and which thus makes possible the calculation of the electric energy necessary for a given change, has provided an accurate foundation for the application of thermodynamics to electrochemistry. Also, by continuing the special conception which gave rise to the theories of osmotic pressure and electrolytic dissociation, a simple conception of electrochemical processes has been developed. It has at the same time become apparent that electrical forces unquestionably play a great part, not only in electrochemical phenomena, but also in many purely chemical reactions.

Thus we are brought to the problem of the nature of chemical forces. Although this question does not perhaps possess the fundamental importance that is often attributed to it, nevertheless it should be briefly considered. It can be treated here still more briefly because we are obliged to admit that during the period under consideration there has been no answer to this question which really tells us anything more than we can see with our own eyes. It seems reasonably certain that we should admit the existence, not only of electrical and therefore polar forces, but of nonpolar natural forces somewhat of the nature of Newtonian gravity. When fluorine and potassium unite to form a salt, the colossal affinity between the two elements depends at any rate in part on the affinity of the fluorine for negative electricity and of the potassium for positive electricity; but when we find in the ordinary nitrogen molecule two atoms of nitrogen united in a combination, perhaps of equal stability, it would appear that in the case of as complete an identity as presented by two atoms of nitrogen the action of polar forces should be entirely excluded. The

fact that polar and nonpolar forces always act simultaneously in the production of chemical combinations is the principal reason why investigators have not yet been able to fathom the nature and the law of chemical forces, and is responsible for the fact that the investigations have not yet gotten away from a consideration of the balance of energy.

There is no need of entering here into that mooted question which has been brought up many times in physical chemistry, the question of the supremacy of the thermodynamic or the atomistic theory. This is perhaps nearly as important as determining whether Schiller or Goethe was the greater man, and should be answered in a like manner: We should rejoice in the possession of two resources so powerful and at the present time so indispensable for scientific thought. The chronicler should, however, make note of the fact that most of the modern results in the domain of physical chemistry have been obtained by a happy combination of thermodynamic methods with molecular theories, such as the creators of the modern theory of heat have followed in devoting most of their work to the development of the atomistic side, particularly of the kinetic theory.

Thermodynamics had its origin in the methods of mathematical physics. The atomic theory, on the contrary, owes its high state of perfection especially to chemical research. We should regard as a result of the latter the application of the atomic theory to the science of electricity which has begun to develop a chemical theory of electricity. There are many reasons for believing that the two forms of electricity are composed of almost infinitely small particles, each identical with the other, called "electrons." Consequently, free ions should be interpreted as combinations between the elements or radicles and the electrons, to which the laws of constant and multiple proportions apply and which likewise are governed by the theory of valence. We must limit, however, this brief indication of how the atomic theory by such a marvelous enlargement of its horizon, has put a number of physical and chemical processes in an entirely new light, and end with a few words on the radio-active emanations whose existence is made clear to us through the electron theory.

The effects of this radiation, according to the prevailing theory, are caused by the projection of electrons either in a free state or bound up with matter, and whose existence is most easily determined by the electroscope. These very recent researches have opened to us the new world of radio-active substances. For sensitiveness this method of research is often superior even to spectral analysis. As an example I may mention the fact that according to the calculations of a young investigator in this field, if a milligram of radium C were divided among all the people living on the earth (about two thousand millions) each one of them would possess an amount sufficient to dis-

charge five electroscopes, sufficient to enable him to study (with a sufficient experimental accuracy) the most important radio-active properties of each element.

The extreme sensitiveness of this reagent for radio-active substances has been the only factor which has permitted the discovery of several radio-active elements which had heretofore escaped notice because of their very small quantity or because of the brief period of their existence (in the sense of the hypothesis of atomic decomposition).

It is often easy to write history, but it is always more difficult to learn anything from the history after it is written. If I dare make a modest attempt in this direction, I should say perhaps that the chemist with such a mass of material to work on is destined in the future to prepare new compounds and to study the reactions of those already known as in the past, but that the methods of experimental and theoretical physics will be more and more called into requisition to supplement purely chemical research.

DEVELOPMENT OF TECHNOLOGICAL CHEMISTRY DURING THE LAST FORTY YEARS.[a]

By O. N. Witt,

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The representatives of chemistry, general and physical, inorganic and organic, have striven in noble emulation to surpass each other in the number and importance of their discoveries. From the laboratories great and small, official and private, the results of research have flowed like the rivulets which, irrigating the well-watered fields, come together in brooks, then in streams and in rivers, bringing fertility to the habitations of men in the valleys. An abundant harvest has been raised on these watered plains, a harvest which has been enthusiastically consumed by the people.

This harvest, the reward of scientific research, the abundant fruit of the patient work of the mind, consists of the applications which contribute to the well-being of the people. This is why technical chemistry is the worthy companion of abstract research in our science. It should prosper when research is flourishing, and the additions to chemical technique, during the last forty years, are a striking proof of the correctness of this assertion.

About the time when the German Chemical Society was founded a period of far-reaching transformation began in industrial chemistry. The industry of mineral acids and alkalis, based on the Leblanc process—the only one which could boast at that time of the title "great chemical industry"—still adhered to its stereotyped operations and to the dependency of its series of steps, one upon the other. But the young Titan which was destined to struggle with and cause its complete rehabilitation—the Solvay process for the production of soda by means of ammonia—had come into existence and was already developing. About 1870 this process appeared to have

[a]Address before the German Chemical Society at the celebration of the fortieth anniversary of the society, November 11, 1907. Translated by permission from Berichten der Deutschen Chemischen Gesellschaft, Jahrgang XXXX. Heft 17. Berlin, 1907, pp. 4644–4652.

reached a productive stage, and it was recognized that the possibility of obtaining soda independently of the Leblanc process would break up the whole continuity of this great chemical industry. It was still protected, however, by the close dependence on it of the production of hydrochloric acid and from this the making of chlorine by the sulphate process, and by the advantages offered by the soluble product of its raw soda in the preparation of caustic soda. In truth, these two circumstances prolonged the life of the Leblanc process for several decades and are responsible for the fact that even yet it has not entirely disappeared.

Toward 1860, almost simultaneously with the development of a commercial process for the production of soda by ammonia, came the inauguration of the potash industry at Stassfurt, which was founded on the fortunate discovery of the deposits of salts there, under the fertile influence of Liebig's wonderful researches.

To the preparation of potassium chloride from carnallite and sylvinite soon was added the preparation of bromine, of potassium nitrate by the use of sodium nitrate, and the manufacture of potash by the Leblanc process, without any danger here of a concurrent process with ammonia. Finally, a successful process was developed for the utilization of part at least of the magnesium compounds which were present in the salt deposits, although the successful extraction of all the magnesium chloride made in the potassium industry is to-day still in the category of unsolved problems.

The year 1870 saw the rejuvenation of the century-old industry of oil of vitriol, the fuming sulphuric acid, whose small content of sulphuric anhydride no longer sufficed for modern needs.

In place of the product obtained by distilling vitriolic schists came synthetic sulphuric anhydride, prepared by the catalytic combination of sulphurous anhydride and oxygen, and the pyrosulphuric acids. This new process of manufacture was to influence and transform the whole sulphuric acid industry to a great extent. It was possible to apply it to advantage more than a quarter of a century later, when the modern contact processes appeared.

The last two decades of the nineteenth century were characterized by the development and application with exceptional rapidity of electro-technics. In the field of chemistry, this new phase of industry voiced itself in the development of electrolytic methods of operation. In the field of electro-metallurgical processes, the most important of which are the preparation of aluminum and the electrolytic refining of copper, which are closely followed by the manufacture of calcium carbide and carborundum, the question of the electrolytic decomposition of alkaline chlorides has been a most warmly discussed problem. The difficult problem of preparing membranes which are more sensitive, and at the same time more resistant, was solved almost simul-

taneously by three processes, that of Griesheim, that of Castner-Keller, and that of Aussig, which are close rivals in their effectiveness and boldness of invention. With these a new era has begun in the production of caustic alkalis, and also in the chlorine industry. The old process for the production of chlorine has disappeared along with the ingenious methods of Weldon and Deacon. Chlorine, once so costly, is produced in such abundance as to provoke a feverish search for new applications for it. By the side of and often in the place of the venerable chloride of lime we find to-day liquefied molecular chlorine put up in transportable form in steel bottles.

Finally, the production of alkali metals on a large scale should be counted as one of the most important results of modern electro-chemical technology. The same reaction in a form suitable to technical methods which once in Davy's hands led to the discovery of these metals—the electrolysis of alkaline hydrates—has shown itself to be the best and least costly method of manufacture for these strongly reactive bodies, one of which especially, sodium, has rapidly become of extensive application in a technical way. By its aid in particular, it has been possible to produce potassium cyanide free from cyanates, which has contributed to the success of the cyanide process for refractory gold ores.

Such a metamorphosis of inorganic chemical technology as has been briefly described would not have been conceivable if greater and greater quantities with their continually decreasing prices had not found a continually increasing market. The same fact along with the natural increase of needs generally has produced in the case of organic chemistry an even more striking and remarkable transformation and development than in inorganic technical processes.

We all know in a general way that the old industries of brewing, distilling, sugar making, and starch making, of the production of fatty bodies and of foods, all of which are connected with agricultural work, have flourished remarkably in the last forty years and have become of very great importance. They owe their most important progress to the aid of modern biological research. But besides these, other industries operating on organic substances have sprung up and prospered, which were formerly entirely unknown.

A lively interest attaches to the chemical application of wood which has not only allowed a particularly profitable use of our forests, which is coming more and more into evidence, but has also led to a simple separation, almost analytical in its nature and carried out on a large scale, of the components of lignine, one of which, however, the incrusting medium, remains to this day a chemical enigma.

The extraction of an almost pure cellulose from wood has placed the paper industry on a new footing and has obviated the necessity of our limiting the production of printed matter for want of paper.

It has led also to the discovery of a number of other useful applications of cellulose, of which I will mention only the preparation by various methods of new artificial textile fibers analogous to silk.

Wood can be worked chemically, however, in another way than by the separation of its content of cellulose. I refer to the process of dry distillation. The very primitive preparation of carbon and wood tar of the old days has developed during the last forty years into the very highly perfected art of wood distillation, which has obtained most important commercial results with decomposition products formerly entirely neglected—methyl alcohol, acetone, and acetic acid. The attempts, first without result, but later crowned with success, to free the ligneous acetic acid from the empyreumatic bodies obtained with it have resulted in the fact that the greater parts of our demands for acetic acid are now supplied by the distillation of wood. This industry received a still further impetus in 1890 by the introduction of a process for the preparation from methyl alcohol of formaldehyde, the production of which has enormously extended since the extraordinary variety of uses to which this new product can be put has been recognized.

Another remarkable method for the treatment of wood, fusing it with alkali for the production of oxalic acid, has not developed, but rather has diminished, in importance during the forty years under consideration. It has been replaced by the synthetic method of preparing this acid, as well as of formic acid, by means of carbon monoxide contained in generator gases. Formic acid can be prepared so advantageously in this way that it is competing with acetic acid in many of its applications.

The commercial utilization of hydrocarbons of the methane series is brought out in two industries—the distillation of lignites and the refining of petroleum. Both of these industries have shown an extraordinary increase in their extent and have displayed numerous marked improvements in their production. Among the latter the desulphurization of fetid petroleum of the Ohio type by distillation over copper oxide should be considered a technical achievement of high rank.

The development of coal distillation and the treatment of tar affords a particularly important and interesting example of progress. When this society was founded only one form of distillation of coal was recognized—its application to the manufacture of illuminating gas, which dates from the end of the eighteenth century. This distillation was carried on at a low temperature and furnished the entire amount of tar produced, the tar which is so important in the recently developed color industry. In 1880 the output of tar began to be less abundant, a fact caused not only by the constant increase in its use in the production of tar dyes, but also to a great

extent by the far-reaching transformation of the gas industry, which, on account of extended and ingeniously interpreted experiments had been developed into an entirely new process, characterized by the employment of high temperatures of distillation. The momentary embarrassment which fell on the dye industry led to the creation, far-reaching in its consequences, of a new industry—distillation for coke, which saves from destruction the riches contained in the by-products of coke manufacture and which frees for a long time the dye industry from any lack of raw materials.

Among the products derived from coal tar may be mentioned anthracene, carbazol, the xylenes and the cresols, coumarone and pyridine, substances whose systematic manufacture is only forty years old and which have found a steady commercial application. Of many of the other of the tar derivatives, some have been only recently discovered, while others have been rendered more available than heretofore.

It is to the improvement in its methods of operation, especially in the apparatus, that the industry of tar distillation owes the thoroughness with which its products may be separated from such a complex mixture as goes to make up tar. Column stills, filter presses, and processes such as vacuum distillation are the means which have enabled the modern tar industry to attain its present position.

The most striking example of an industry working hand in hand with scientific research, profitably applying all its results and influencing them in its turn, is afforded by the manufacture of coal-tar colors. It is almost impossible to touch in these few words on the most important stages of the triumphal progress of this industry.

We may say that the foundation of the German Chemical Society was coincident with the date when the newly founded color industry was emancipated from empirical methods and turned toward scientific synthesis. The first great success obtained through this agency was the creation of the alizarin industry, whose later development has surpassed all expectations. The recognition of the close connection between constitution and properties of coloring matters found its practical application in the introduction of azo dyes, which not only brought into the industry an extraordinary variety of colors, but accustomed the dye chemist to develop almost quantitative methods of work. In the group of phthaleins were found not only some of the most striking coloring materials, but also some of the most permanent, thus refuting the theory, not proved, but then current, that artificial colors were ephemeral in the same proportion that they were brilliant. Equally permanent dyes were found among the eurhodines, safranines, oxazines, indulines, and thionines, the study of which is so intimately bound up in that of nitrogen chains and the joining of nuclei. The discovery by a mere chance of a fast alizarin blue, so

important from a technological point of view, likewise carried in its wake great consequences for scientific chemistry, for the investigation of the composition of this dye led to a synthesis, capable of general application, of the derivatives of quinoline. In a like manner the explanation of the constitution of rosaniline was very productive in allowing the synthesis of numerous new compounds, among which are found some of the most beautiful and valuable dyeing materials.

The appearance of substantive azo colors, and finally of those known as "sulphonated dyes," has not occasioned the opening of any new avenues of scientific investigation. These two accomplishments, however, are of the greatest importance in that they have provided new methods for dyeing and printing and have completely revolutionized these two ancient industries.

Lastly, we may mention the new class of indanthrene colors in which are united clear tints with an hitherto unknown resistance to all destructive influences.

It is the synthesis of indigo, however, that we must hail as the most brilliant of all the conquests in the field of coloring materials. We can still recall the day when the great event in chemical history was made public and when every hand was extended in congratulation for this masterpiece of scientific research. The struggle for a solution to this great problem cost twenty years of assiduous labor, but, once solved, how well the new product of synthetic indigo has stood the test beside the natural product backed by several thousand years' use.

There is no hope that this industrial triumph in the coloring field will ever be surpassed. It is none the less certain, however, that this industry has not yet attained the limit of its development. Our reviews in the future will still record many achievements bearing witness to the uninterrupted development of this interesting and manifold branch of technology.

We may consider the manufacture of synthetic medical preparations as an offshoot of the color industry which sprang up in the period we are considering and which has already earned a position of its own. What brilliant results have been accomplished in this field, also. What a beautiful gradation of development from complex insufficiency to simple perfection can be witnessed in comparing kairine and thalline on one side and antipyrine, phenacetine, and aspirine on the other. What a progress in the regulation of physiological functions is evidenced in chloral hydrate and veronal. What pains has not synthetic chemistry soothed by its activity in this field, what ills has not it assuaged.

The industry of artificial medicines is only one of a vast circle of varied activities which we are in the habit of grouping together under the collective term of preparation industries. To properly appreci-

ate this industry with all its ramifications is impossible. Nevertheless I can not help mentioning the appreciable growth of a branch of this industry which is almost as old as this society. This is the manufacture of chemical products and preparations for photography, whose expansion has been closely connected with the development of scientific photochemistry and with the introduction and popularization of dry photographic plates with their proper processes of development.

Not less interesting are the chemical and technical aspects of the perfumes newly created and developed during the last forty years. This field, which is completely developed along its principal lines at the present day, was still unexplored at the time when the German Chemical Society was founded. Its expansion is reflected more completely in the pages of our transactions than anywhere else. Step by step nature has been imitated in its creations, and in this field perhaps more than anywhere else the synthetic chemist has taken paths which follow those of nature.

Among synthetic industries we should count the technology of explosives, although here it is a matter less of constructing molecules than of storing up energy in a form easily liberated. In this industry great progress has been recorded, almost all of which depends on the utilization of the facts expressed by the law of Sprengel, expounded about forty years ago, and on the employment more and more of safe explosives which can be detonated only by an initial ignition, in place of bodies themselves explosive. The possession of such explosives and the application to the phenomena of explosion of modern methods of observation have alone made possible the new orientation in ballistics, which is well known to all of us.

If we consider all this technological progress that I have mentioned and much more which I must refrain from describing, we must agree that as far as applications are considered our science has reached a high state of development. But just as scientific research, in spite of the abundance of results, still presses forward, so will technology not stand still, but will continue to attack more and more difficult problems.

When this society was founded there was already, it is true, a very well-developed series of chemical industries, but their activities were limited almost entirely to the extraction, purification, and transformation of natural products. An industry operating synthetically on a large scale is a development solely of the last forty years. Today we are striving for even more lofty ends. We have dared to lay a hardy hand even on the great processes of nature in seeking to influence them according to our needs. It is this that we behold in the great factories where many are striving to utilize the nitrogen of the air. Many methods have been proposed to attain this end;

the combustion of nitrogen to its oxides and the transformation of it into cyanogen or ammoniacal compounds have been used. All these methods are practicable and will all probably be productive of results. Which of these results will be the most important it is for the future to decide. In all of them, however, is this characteristic feature—they do not rob Nature of its amassed treasures, nor do they wish to imitate her creations; they aim merely to assist her in one of her greatest processes, the circulation of nitrogen. If we succeed in influencing this phenomenon, we will also in a measure control that other which is so intimately bound up with our fortune or misfortune, the course of life. We will force the earth to greater fertility, to an increasing habitability.

In such a task Nature herself should be our ally. The savage force of the water which falls from above carries out the chemical work which we call upon it to perform, and a day is beginning to dawn when it will be not only a pretty metaphor, but one of peculiar force and meaning, to speak of the fertile influence of the brooks which ripple down from the mountains into the valleys where stand the habitations of men.

TWENTY YEARS' PROGRESS IN EXPLOSIVES.[a]

[With 9 plates.]

By Oscar Guttmann, M. Inst. C. E., F. I. C., F. C. S.

I.

From the time of the invention of gunpowder, or approximately in the year 1250 (Roger Bacon at any rate knew of it in 1264), until the beginning of the nineteenth century no other explosive was introduced into practice, although picric acid and fulminate of mercury were known about the latter date. Experiments were carried out by Le Blond in 1756 in the French Government factory at Essonne to produce gunpowder without sulphur, and a British patent for a powder containing "coal brasses" and without charcoal was taken out by Delaval in 1766,[b] but that was all. In 1788 Berthollet and Lavoisier tried the effect of adding potassium chlorate, and in 1861 Designolle made a powder from potassium picrate and saltpeter, but without much success. In 1846 Schoenbein invented gun cotton, and Sobrero in 1847 nitroglycerin, but the Austrian Government, which was the only one to try gun cotton in guns, stopped the experiments abruptly in 1867, their magazines at Hirtenberg having blown up, and, curiously enough, it is not until that date that Nobel began to work on dynamite. About the same time the British Government began to experiment with gun cotton at the point where the Austrians had left off, and introduced it as a blasting agent into the service, their example being then followed by other governments. In 1873 Sprengel made his well-known communication to the chemical society "on a new class of explosives," which has since been named after him; and in 1878 it was again Nobel who invented blasting gelatine. About 1864 Abel and Doctor Kellner, of Woolwich Arsenal, made a granular gunpowder from gun cotton, and at the same time a sporting powder

[a] Reprinted, by permission, with abridgment by the author, from Journal of the Royal Society of Arts, London, Nos. 2927, 2928, 2929, Vol. LVII, December 25, 1908, January 1 and 8, 1909, and from volume "The Manufacture of Explosives. Twenty Years' Progress." Whittaker & Co., London and New York, 1909.

[b] Thomas Delaval, British patent No. 846, of 1766.

from nitrated wood, the Schultze powder, was introduced. Later on, in 1882, Reid made grains of soluble gun cotton, and hardened them by means of ether alcohol, calling the product "E. C. powder." In the third lecture reference will be made to the important smokeless powder of Friedrich Volkmann made in 1870.

Such was the state of the art in 1886, when simultaneously Eugène Turpin, of Paris, suggested the use of compressed or molten picric acid as a charge for shells, and Vieille carried out his famous experiments, resulting in the manufacture of the Poudre B (so named after General Boulanger). At the same time it was recognized that most explosions in coal mines were due to the ignition of fire-damp by the firing of shots, and that it was possible to make so-called "safety explosives," which would considerably reduce this danger.

Hereafter investigations and inventions came in almost too rapid succession. Unfreezable dynamites, dinitroglycerin explosives, picric acid compounds and trinitrotoluene explosives, fulminates from aromatic nitro-compounds, phlegmatized fulminate, detonating fuses, and many other varieties were invented. Nitrocellulose, than which there is hardly a more complex substance, was investigated by Cross and Bevan, Häusermann, Lunge, de Mosenthal, Vignon, Will, and others; the stability of nitro-compounds, the properties of nitroglycerin, and many other substances investigated by an army of workers. In fact, quite as important results have been obtained since 1886 as in the whole of the previous years. This is due, in the first instance, to the enormous amount of scientific research and experiment devoted by manufacturers to the study of such questions, partly because they were forced to do so by considerations of national defense, the advent of the rock drill, and by competition, and partly because those who lacked the training for such research could be persuaded by the results achieved to appreciate the work of others. Whilst until a generation ago the so-called "powder maker" was a craftsman, who carefully guarded little tours-de-main as valuable trade secrets, and even the inventors of high explosives had to advance in a most empirical way, it is recognized nowadays that only the best scientific knowledge can effect improvements or keep in line with modern developments of the industry.

Whilst for warlike purposes the use of black powder, and even that of the later brown powder, has become a negligible quantity, blasting powder is still sold to such an extent that in the mines and quarries of this country alone nearly 7,000 tons of it, or more than half the total weight of all explosives, were used in 1907.[a] This of course represents only part of the total quantity manufactured in this country, since 3,597 tons of gunpowder of all kinds of British and Irish

[a] Report of His Majesty's inspectors of explosives for 1907.

production were exported,[a] and a good deal was used for railways, roads, etc.

There has been practically no progress made in black powder within the last twenty years. Brown powder, which, as is known, contained slack burnt charcoal and a small percentage of sulphur, greatly improved the shooting of large guns, but has gradually given way to smokeless powder, even for the very largest guns. A little black powder is still used as a primer for large charges, but even for that purpose it will gradually be replaced by specially prepared smokeless powder. There are still some old sportsmen who prefer to use nothing but the old fine black sporting powder, and this is more especially the case in remote parts of Germany, Austria, and Italy, whilst in the United States of America professional sportsmen, i. e., those who shoot wild fowl for the market, use black powder because of its cheapness. There is a certain amount of competition going on in this quarter with smokeless powder, and manufacturers of black sporting powder are thereby obliged to make special efforts to produce material of the highest grade only.

The enormous development of the German potash industry, and the peculiar requirements of potash and salt mining, have also revived some rough mixtures of black-powder-like explosives, of which very large quantities are now sold in Germany.

In America, also, large quantities of black powder made with sodium nitrate are used. Labor there is so expensive that work is done with this cheap explosive which on this side of the Atlantic would be carried out with pick and shovel.

Progress of a different kind has been effected by using ammonium nitrate as an ingredient in a powder mixture. This also was tried in France in the eighteenth century with but little result.[b] Amide powder,[c] however, made by the Koeln-Rottweil works, and consisting of 40 parts of potassium nitrate, 38 parts of ammonium nitrate, and 22 parts of charcoal, might, but for the advent of smokeless powder, have become a serious rival to black powder. Mayer, of Felixdorf, in Austria, also worked in this direction. The Austrian Government makes Wetter-Dynammon as an explosive for fiery mines, which, according to Ulzer,[d] consists of 93.83 per cent of ammonium nitrate, 1.98 per cent potassium nitrate, 3.77 per cent charcoal, and 0.42 per cent moisture, the charcoal grains being 1 to 6 μ in size.

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[a] Private communication.

[b] Bottée et Riffault, "Traité de l'art de fabriquer la poudre à canon." Paris, 1811.

[c] Gaens, British patent No. 14412, of 1885.

[d] "Mitteilungen des technologischen Gewerbemuseums." Wein. 1900, p. 204.

Further progress, although seemingly small, has been that made in powder for safety fuses. Formerly it was not uncommon to use the siftings from mining powder for safety fuses, but the present stringent requirements have compelled all manufacturers to make a special quality of fuse powder of constant composition, density, and uniformity of granulation, in spite of its almost dustlike character.

I shall lay before you later on some information concerning safety explosives for fiery mines, and, therefore, will only mention that in every European country the use of gunpowder is prohibited in such workings. Considerable surprise was therefore felt when several black-powder-like mixtures passed the official test for permitted explosives in this country. Later, when these tests were made more rigorous, these explosives disappeared, but one of them, bobbinite, passed even the more stringent tests, and is still on the new list of permitted explosives.

Complaints having been made as to the alleged danger of bobbinite in fiery mines, the home office appointed a departmental committee in 1906 to investigate the matter, which came to the conclusion that the use of bobbinite should not for the present be restricted.[a] The importance of this explosive may be gauged from the fact that over a million pounds of bobbinite were used in 1907 in this country.

With regard to machinery used in the manufacture of black powder and similar mixtures there has, of course, been very little improvement. Mixing, granulating, and glazing are still carried out in the same way, and for the purpose which they have to accomplish the machines do all that can be desired. A good deal of ebonite was formerly used in connection with machinery for black powder, such as for plates in cake presses, for lining the hoppers of cutting machines, etc. In cake presses there are alternate layers of powder containing sulphur, and of highly insulating ebonite, which remain together under pressure for some time. It is a rule in explosives works that at the approach of a thunderstorm the workers leave their houses, and it is frequently found convenient, meanwhile, to leave the charge under pressure. This would practically constitute an electric pile, and as a matter of fact several explosions have occurred when, after the thunderstorm, the workers opened the presses. In one instance, at least, the fact of a long spark having come out of the charge could be elicited from the attendant before his death.

Following a suggestion made by the author twenty years ago, a number of factories have substituted plates of fiber for these ebonite plates with great success.

[a] Report of the Departmental Committee on Bobbinite. London, 1907.

Chlorate mixtures have at all times fascinated inventors on account of the large amount of oxygen stored up in potassium chlorate, which can be given off so readily. When Lavoisier and Berthollet tried to make a chlorate powder in a stamp mill in 1788, they made a great show of it, and even two ladies were present. Unfortunately after a certain amount of pounding the powder exploded and killed an official and the daughter of the government commissary, who assisted at the experiments.

In this country we have for a long time refrained from licensing any explosive containing potassium chlorate, because such are so sily exploded by impact or friction. With the advent of electrolytic methods for the manufacture of chlorine, potassium chlorate, and the like, chlorate explosives were brought within easy reach of the trade, and in fact the present price of electrolytic potassium chlorate will under certain conditions permit the economical manufacture of suitable explosives. Hence greater efforts were made to render chlorate explosives more stable, so as to pass the home office test, and ultimately success was attained by the addition of some oil. Its function is evidently to so surround the potassium chlorate that, when mixed with carbonaceous matter, it becomes less sensitive. The addition of greasy matter to chlorate explosives is not at all a new idea. In 1867 already F. Hahn added spermaceti to a gunpowder containing chlorate.[a] However, a practical explosive was ultimately obtained in cheddite, patented by Mr. Street,[b] and so called because it was first made in Chedd, in Switzerland. The more usual variety is known abroad under the name of cheddite 60 bis, and its composition is 80 parts of potassium chlorate, 13 parts of mononitronaphthalene, 2 parts of dinitrotoluene and 5 parts of castor oil, whilst in this country the proportions of mononitronaphthalene and dinitrotoluene are reversed.

It is interesting to observe how the same old mixtures are proposed over and over again with slight alterations only, in order to qualify for a patent. Potassium chlorate with some carbonaceous matter like charcoal, sugar, starch, glycerin, flour, or sometimes a vegetable or mineral oil and the like occurs again and again. One patent[c] is of special historical interest, since it proposes the use of "Maltha" as an ingredient. The patentees came from California, an English-speaking country, and therefore it might be supposed that the name was not unfamiliar in England, but this appears not to be the case. I recollected, however, a passage in Roger Bacon's "Opus Majus" as follows: "Nam Malta, quæ est genus bituminis et est in magna copia in hoc mundo, proiecta super hominem armatum comburit

[a] British patent No. 960, of 1867.

[b] Id., No. 9970, of 1897.

[c] Quinby, Sharps and Greger, British patent No. 4781, of 1902.

eum "—(Thus Malta, which is a kind of bitumen, and exists in large quantities in this world, when thrown on an armor-clad man, burns him to death). It seems, therefore, that the *Mayflower* took with her some Old World expressions and adapted them to the New World.

The latest surprise is that in 1908 a chlorate explosive has been licensed as a safety explosive in this country under the name of "colliery steelite;" it consists of 74 parts of potassium chlorate, 25 parts of oxidized resin, and 1 part of castor oil.

The electrolytic chlorine industry has also made possible the manufacture of pure perchlorates, and more especially of ammonium perchlorate, which presents many advantages, although the objection has been raised that explosives containing this ingredient generate fumes of hydrochloric acid in the mine.

Another class of explosives, which was from time to time used for ordinary blasting purposes, and of which very little has been heard in this country, are the Sprengel explosives. You have all heard of rackarock, which was employed in the blasting of the Hell Gate rocks near New York. Until the last decade it was hardly used anywhere except in America, but on building the first Chinese railways the Americans were able to introduce it.[a]

A novel ingredient was introduced by Winand,[b] who mixes tetranitromethane with petroleum or other carbonaceous matter.

A new departure was made in 1899, when Dr. Richard Escales, of Munich, invented the first aluminum explosive. There were only a few early attempts to utilize light metals in explosives, until Escales showed that the addition of aluminum or magnesium very considerably increased the temperature of explosion and thereby the explosive force. His explosive was patented under the name of Wenghoffer,[c] and is now, I believe, manufactured, together with a similar explosive invented independently in 1900 by Ritter von Dahmen,[d] and since known under the name of "ammonal."

Ever since aluminum has been taken as an ingredient in almost any kind of explosive. Theoretically it would be of very great value, but in practice the high price of aluminum powder and the possibility of oxidation under suitable conditions have somewhat militated against it. It is, however, used in Austria-Hungary for filling shells, for which purpose it seems well suited, not having given any trouble during ten years of storage, although I am told they sometimes fail to explode. It is also on the special list of the British home office as an explosive for fiery mines.

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[a] Károly Gubányi, "The Rackarock Blasting Powder," "Magyar mérnök és épitész egylet közlönye," 1901, p. 165.

[b] British patent No. 26261, of 1907.

[c] British patent No. 24377, of 1899.

[d] Id., No. 16277, of 1900.

Other metals might have a similar or even a better effect than aluminum. Thus in 1900 already Désiré Korda, of Paris, and the author have considered the possibility of using ferro-silicon. In addition to the above-mentioned metals, the use of iron, silicon, silicon carbide, zinc and its alloys, copper, and also the rare metals has been patented.

In his patent of 1871 on the explosives bearing his name,[a] Prof. Hermann Sprengel, F. R. S., said, seemingly without reference to the rest of the patent, "I also employ picric acid," but in his famous lecture delivered in 1873 before the Chemical Society he said distinctly: "Be it noticed here that picric acid alone contains a sufficient amount of available oxygen to render it, without the help of foreign oxidizers, a powerful explosive, when fired by a detonator. Its explosion is almost unaccompanied by smoke." As a matter of fact, Sprengel did fire some shots with picric acid at Messrs. John Hall & Sons' factory in Faversham in 1871, but was not encouraged by the service to pursue his experiments.

Nothing further was heard of picric acid until 1886, when, as mentioned before, Eugène Turpin, of Paris, showed how to compress or melt it for use in shells. The French service used picric acid, mixed with collodion to give it greater density, under the name of melinite. Later on it was compressed, but ordinary detonators failed to explode it with safety, and the expedient devised by Alberts and the author to use a primer of dry gun cotton was too inconvenient. The picric acid has therefore to be melted, in which state it can be more readily exploded by detonators, and has a density of about 1.65. Picric acid melts at 122.5° C., and must therefore be either heated in an oil bath by high-pressure steam or in a special "stove." Melting it at such a high temperature is very inconvenient and is not without danger, hence use was made of the well-known phenomenon that a mixture of two substances of high melting points has nearly always a lower melting point than that of either of its constituents. Girard[b] has given a long list of the melting points of explosive mixtures of this kind.

Almost every country has adopted picric acid as a disruptive agent, under a different name, and differences in composition consist merely in the addition of an ingredient to reduce the melting point. Such additions are nitronaphthalene, camphor, dinitrotoluene, etc., and the names are melinite, lyddite, pertite, shimose powder, picrinit, ecrasit, etc.

Besides having a high melting point, picric acid is inconvenient in other ways. Left in contact with metals or oxides it forms very dangerous picrates, hence the necessity of varnishing the interior of

[a] British patent No. 2642, of 1871.

[b] Id., No. 6045, of 1905.

shells, giving special protection to the primers, and generally taking the utmost precaution to prevent access of foreign bodies while the acid is in the molten state. Picric acid has an intensely bitter taste (which is still more pronounced in the inky black smoke of burning picric acid), and therefore its manipulation is not very pleasant. It also imparts a fairly fast yellow coloration to the skin, which in some parts has procured the nickname of "canary birds" to the workers in picric acid. (I have found that in one factory common salt was used for removing the yellow coloration from the skin, but why it should do so is not quite clear.) When used together with other materials it must be remembered that, being an acid, it is liable to displace other acids; for instance, it sets free nitric acid from nitrates, and therefore while picric acid might be useful for increasing the power of certain explosives it would actually decompose them.

In order to obviate these drawbacks Hauff had proposed the use of trinitroresorcine[a] and the Chemische Fabrik Griesheim that of trinitrobenzine[b] and trinitrobenzoic acid.[c] These substances were not favorably received, but trinitrotoluene has within the last few years come very much to the fore, and also possesses a great many good qualities. Its melting point varies between 72° and 82° C. It may be handled with almost perfect safety if pure, does not give off noxious fumes on melting, is quite stable, does not combine with metals, and generally has no acid properties. Like picric acid it is only slightly soluble in cold water. It is slightly less powerful than picric acid, which is rather an advantage, since the latter frequently pulverises a shell, instead of bursting it into a number of fragments sufficiently large to have destructive effect. Trinitrotoluene is very easily detonated. I have been able to explode it in the form of powder, with a No. 3 detonator only (0.540 gram of fulminate composition).

Trinitrotoluene has been introduced into the French service under the name of tolite. The Spanish Government call it trilit. The carbonite works of Schlebusch are introducing it into other services under the name of trotyl, and Messrs. A. and W. Allendorf, of Schoenebeck, under the name of trinol, whilst other factories retain the name of trinitrotoluol.

The manufacture of trinitrotoluene is carried out in stages, like that of most aromatic nitro compounds. Great care has to be taken to purify the toluene, since that usually found in commerce contains benzine and other compounds. Nitration is effected in enameled iron vessels, and purification of the higher nitrates, which cake together during nitration, has to be performed with some care. Wash-

[a] British patent No. 9798, of 1894.

[b] German patent No. 79477, of 1893.

[c] Id., No. 79314, of 1893.

ing is usually completed in centrifugals. In order to obtain the best quality, melting between 81° and 82° C., trinitrotoluene made from purified toluene, and having a melting point of 77° to 79° C., is recrystallized from alcohol in vacuo. The machinery for effecting this is not very complicated, but always specially designed. In this country alcohol is somewhat dear and inconvenient to use, in spite of facilities afforded for obtaining it duty free, and petroleum benzine is therefore employed for recrystallizing the trinitrotoluene; it is said, however, that a slightly darker color is imparted by this method to the product, to which objection is taken in some countries.

The density of trinitrotoluene when loose being 1.50 and when molten 1.600, means have been devised to increase it. Rudeloff [a] obtains a density of 1.85 to 1.90 by making a plastic substance from trinitrotoluene and potassium chlorate with a gelatine made from dinitrotoluene and soluble nitrocellulose. Bichel makes a plastic compound with collodion cotton, liquid dinitrotoluene, and larch turpentine, calling it plastrotyl.[b] Messrs. Allendorff mix the trinitrotoluene, together with some lead nitrate or chlorate, with a gelatine made from dinitrotoluene and nitrocellulose, and call it triplastit. This is an improvement on the way the French Government made melinite with collodion, or Wolff & Co. filled gun-cotton slabs into shells with paraffin wax. Bichel also melts the trinitrotoluene, and after first exhausting all occluded air, compresses it by introducing compressed air above it.[c] Bichel has in this way obtained densities up to 1.69. Rudeloff presses it in hydraulic presses under a pressure of 2,000 to 3,000 atmospheres, whereby it obtains a density of 1.7, and can be cut and worked like gun cotton. For the purpose of facilitating detonation, some loose trinitrotoluene is used as a primer. Trinitrotoluene is also used in detonators, of which further mention will be made later on.

Another new explosive for filling shells is used in Spain under the name of tetralit.[d] It is said to be made from tetranitromethylamine, and to be more sensitive than trinitrotoluene, but very little else is known.

During the last three or four years newspapers contained accounts of trials with a new explosive, at first called vigorite and now bavarite, the invention of Professor Schulz and Mr. Gehre, which is said to cost only one-third as much as other explosives, and to be ever so much more powerful. On examining the patent [e] one finds that this

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[a] "Zeitschrift für das gesamte Schiess- und Sprengstoffwesen," 1907, p. 7.

[b] British patent No. 16882, of 1906.

[c] Id., No. 19215, of 1906.

[d] "Zeitschrift für das gesamte Schiess- und Sprengstoffwesen," 1908, p. 308.

[e] British patent No. 5687, of 1905.

is nitrated solvent naphtha. It must be embarrassing to the inventors to see such improbable accounts of manufacturing costs and exaggerated effects produced by the explosive published in newspapers.

II.

I have mentioned in my previous lecture that Sobrero invented nitroglycerin in 1847. It is known that, although he recognized the value of this invention for civil and military blasting purposes, practically no use was made of it until 1867, when Alfred Nobel invented dynamite, and was not deterred by accidents and prejudice from introducing it into the service of mankind. You know that before this time Mowbray, in Massachusetts, manufactured nitroglycerin and carried it into the mines in the frozen state.

Nobel devised processes for the manufacture of nitroglycerin on a large scale, and the machinery for it was constructed to his ideas by his lifelong adjutant, Mr. Alarik Liedbeck, of Stockholm. Since there is a full description of all the apparatus in use in my book on The Manufacture of Explosives, which appeared in 1895, I can confine myself to dealing with progress made since that date. You will find described in this book two kinds of apparatus for nitrating glycerin, such that have a helical revolving stirrer for mixing purposes and such that are agitated by compressed air. Occasionally both mechanical and compressed air stirring are used. One has learned in time to control the operation of nitration more efficiently, and this inspired confidence to increase the size of the apparatus. I believe the largest apparatus made in lead nitrates 680 kilograms of glycerin at one operation, while in America and South Africa steel apparatus with mechanical stirring gear are mostly used, some nitrating 1,000 kilograms at a time. In one United States works they have gone so far as to have four such steel nitrators, each for a charge of 1,000 pounds of glycerin, in one room and driven from one main shaft, but present practice is to have two such nitrators in one building. In this country one would not allow more than one nitrating apparatus to be used at a time. Of course each nitrator is provided with a series of lead or steel coils through which cold water circulates, and it has now become frequent to install a refrigerating plant and to circulate water of only 10° C. and less through the coils.

With regard to the composition of the nitrating mixture, it has been customary in well-conducted factories during the last twenty years or so to nitrate 110 kilograms of glycerin in a mixture of 300 kilograms of nitric acid of about 93 to 94 per cent monohydrate and 500 kilograms of sulphuric acid of 96 per cent monohydrate (and not, as Sir Frederic Nathan and Mr. Rintoul stated, 100 parts of glycerin

and nitric acid of 91 per cent only).[a] This corresponds to about 255 parts of nitric acid monohydrate and 436.4 parts of sulphuric acid monohydrate, or a total of 691.4 parts of acid monohydrate with 35.8 parts of H_2O (4.9 per cent) to each 100 parts of glycerin.

It is now customary to add sulphuric acid entaining 20 per cent of anhydride (oleum) to the original mixture, but it is still found impracticable to add it to the waste acid. It will be seen from the paper of Sir Frederic Nathan and Mr. Rintoul on "Nitroglycerin and its manufacture" that the use of anhydride has reduced the quantity of sulphuric acid required. Five years ago already I found in the Pozsony factory of Nobel's the use of mixed acid consisting of 37.2 per cent HNO_3, 60 per cent H_2SO_4, and 2.8 per cent H_2O, and made with anhydride. Although no artificial refrigeration was used, the yield of nitroglycerin amounted to 220 for 100 glycerin, and a ratio 6.318 of acid to 1 of glycerin. Factories using Nathan, Thomson, and Rintoul's process now employ a mixture of 41 per cent HNO_3, 57.5 per cent H_2SO_4, and 1.5 per cent H_2O, corresponding to 250 pounds HNO_3, 350 pounds H_2SO_4, and 9 pounds H_2O for each 100 pounds of glycerin, which gives a ratio of 6.09 of acid to 1 of glycerin, as against 6.91 to 1 formerly required. It is thus seen that this process requires about the same quantity of nitric acid per 100 glycerin as the old process, but about 86 pounds, or roughly 20 per cent, less sulphuric acid. It will therefore simply depend upon the price of the sulphuric anhydride whether it is advantageous to use it.

With the present prices of £3 per ton of 96 per cent sulphuric acid and £3 15s. 0d. per ton of sulphuric monohydrate, containing 20 per cent of anhydride, the difference between the cost of materials with the former yield of 220 and the present one of 229 nitroglycerin is, per ton, £3 0s. 2d, or approximately 5.6 per cent.

This apparent saving is quite counterbalanced by the fact that in the new process 1.9 tons less of waste acid are obtained.

In making this comparison it must, however, be remembered that with the new process the same apparatus will hold 18 per cent larger charges.

After nitration the mixture is allowed to stand, when the nitroglycerin separates from the waste acid and floats on the top of it. The separation is sometimes considerably delayed by the formation of a silicious colloid, which agglomerates with particles of cell substance and other impurities, forming fern-like growths. The Dynamit Actiengesellschaft in Hamburg[b] found a very efficient means of promoting separation in the addition of high-boiling paraffins in

[a] Journal of the Society of Chemical Industry, March 16, 1908. Compare also Guttmann, Manufacture of Explosives, Vol. II, p. 93.

[b] British patent No. 13562, of 1904.

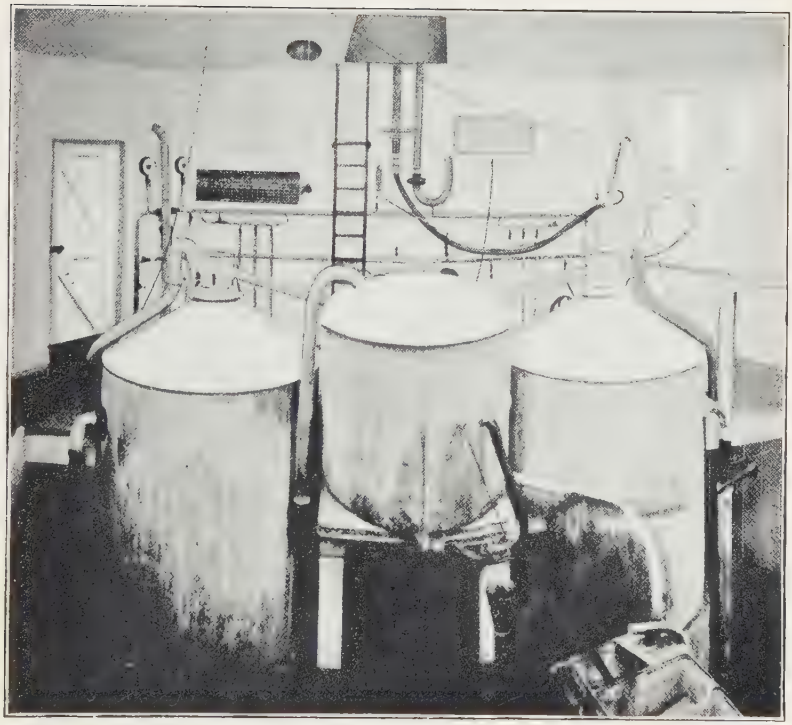
quantities of 0.5 to 2 per cent of the weight of glycerin, while Dr. L. F. Reese, of Wilmington,[a] adds as little sodium fluoride as 0.002 per cent (1 in 50,000) of the glycerin employed to the nitrating mixture with excellent results. Both methods are now used in very large factories. For more than thirty years some factories had been in the habit of employing one vessel only for both nitrating and separating, and withdrew the nitroglycerin from three earthenware cocks, placed at short intervals at the separating line. This enabled them to gain considerably in levels and to carry out the manufacture right up to the final washing on practically the same level.

The waste acid was always sent to after-separation houses, which were frequently called by the German name of "Nachscheidung." Since the waste acid sometimes had to be kept in these after-separation houses for a week, in order to get rid of all the drops of nitroglycerin which separated out, decomposition occasionally set in. A plan was thereupon introduced in France and elsewhere which consisted in gradually diluting the waste acid by the addition of from 2 to 3 per cent of water, thereby stopping the further formation and separation of nitroglycerin.

At the government factory at Waltham Abbey these methods have been improved upon. A so-called "nitrator separator" is used, in which the nitroglycerin has time to separate from the acids, and waste acid is then added from below, thereby bringing the level of the nitroglycerin to a point where it will run out through a gutter into the preliminary washing tank. In this way the use of cocks is avoided. When all the nitroglycerin has been displaced about 2 per cent of water is introduced gradually.

The result of this combination of a number of useful processes, namely, the employment of anhydrous sulphuric acid to produce a mixed acid containing little water, the use of refrigerated water to cool the acids, the displacement of the nitroglycerin by means of waste acid, which obviated the remixing of acid and nitroglycerin on emptying the nitrator, and the addition of water to stop the separation of further quantities of nitroglycerin, was that they together contributed to yield much better results. As a matter of fact in well-conducted works the yield of nitroglycerin with the proportions of 6.91 to 1 mentioned above was between 217 and 220; at Waltham Abbey it was possible to obtain by the "displacement process" a yield of 229 parts nitroglycerin for 100 parts glycerin, instead of the former 220 parts. According to Mr. de Mosenthal the Nobel works obtained similar good results. This yield has to the author's knowledge been only once exceeded in a Belgian factory, when a charge of nitroglycerin had to be drowned on a cold winter's

[a] British patent No. 20310, of 1905.



NITRATOR SEPARATOR (NATHAN, THOMSON, AND RINTOUL'S PATENT).

CALCINED KIESELGUHR.

day. The contents of the tank froze and required two days to thaw; a yield of 240 parts nitroglycerin was, however, the surprising result.

With regard to the selection of apparatus, round lead or steel tanks, as explained above, are generally used, but the author has also seen square-cornered ones. The Americans are much in favor of mechanical stirring, whilst in Europe air stirring is preferred. Having worked with both, I can not see much difference as regards results, but since I do not like to have any moving parts in connection with the manufacture of nitroglycerin I think air stirring is preferable, on the whole.

There has been no special improvement in the manufacture of dynamite since Nobel in 1875 invented blasting gelatin.

In this connection it will be interesting to have a true picture of kieselguhr as used for dynamite. Mr. Henry de Mosenthal, whose skill in preparing specimens for the microscope we had often occasion to admire, has prepared for me various slides of kieselguhr.

For blasting gelatin, as you know, a so-called "collodion cotton" or soluble nitrocellulose is employed. Many people think that if 7 per cent of nitrocellulose is insufficient to make a stiff and suitable blasting gelatin, the addition of another 1 or 2 per cent would do it, and certainly at first the resulting gelatin is so stiff and hard as to require special effort in the cartridge machines. After a few months of storage, however, or after passing over the equator into Australia, nitroglycerin is found to exude. A good nitrocellulose will give a perfectly stiff blasting gelatin, with between 6 and 7 per cent of nitrocotton, and if a 2½ per cent solution is made in a porcelain basin, the resulting gelatine should be easily detachable after cooling, showing no signs of exudation.

There has been within recent years a revival of old ideas, but with better success, for the purpose of obviating one of the chief objections to dynamite, namely, that of freezing. It was in 1866, in Sweden, that A. E. Rudberg patented the addition of nitrobenzine to nitroglycerin for the purpose of making it unfreezable.[a] The Société des Poudres et Dynamites, of Arendonck, found later[b] that the addition of dinitrotoluene dissolved in nitroglycerin was very useful in lowering the freezing point. A new departure was really made when Dr. Anton Mikolajczak in 1904 patented the addition of dinitroglycerin to trinitroglycerin explosives, and at the same time indicated a practical method of manufacturing it.[c] It is now made on a large scale in a factory at Castrop, in Germany. In order to understand the question better it is necessary to point to a most interesting work

[a] Swedish patent, April 30, 1866.

[b] British patent, No. 14827, of 1903.

[c] Id., No. 8041, of 1904.

by Sigurd Nauckhoff,[a] showing why nitroglycerin can sometimes be subjected to intense cooling without freezing (supercooling), and to a paper by Dr. H. Kast,[b] showing that there are two kinds of nitroglycerin (one being an allotropic modification), with two different melting points, one nitroglycerin solidifying at about 13.2° and the other at about 2.1°, the melting points being 13.5° and 2.5°, respectively.

Professor Will found that dinitroglycerin is not a sure guaranty against solidification, and that under certain conditions explosives prepared with it may become solid at a higher temperature than trinitroglycerin explosives.

Of all these additions none has so far been definitely adopted for the manufacture of unfreezable dynamites, but, I believe that lately dinitrodichlorhydrine has been used with considerable success by the German works of the Nobel companies.

We now come to gun cotton. The really important step in the manufacture of gun cotton was taken when the British Government adopted a process of pulping and purifying the gun cotton, first patented by John Tonkin, jr., of Poole, near Copperhouse, in Cornwall,[c] and again in combination with the compression of the pulped gun cotton, three years later, by Sir Frederick Abel.[d] The next step was made when the principle of the detonation of nitrocompounds by means of a small fulminate of mercury charge, invented by Alfred Nobel,[e] was extended by Mr. Brown, Sir Frederick Abel's assistant, to gun cotton.[f]

Baron von Lenck, the Austrian general, who worked most assiduously as the pioneer of Schönbein's invention, used gun cotton in hanks; the British Government introduced the use of cotton waste from spinning and other operations where threads are made. The reason for this change is not quite apparent, unless it was felt that since the cotton had to be pulped in any case the cheaper waste might do just as well as the long threads. This use of cotton waste has continued ever since.

It is very curious that in the purchase and use of nitric and sulphuric acid for the nitration of gun cotton most stringent conditions are laid down with regard to freedom from mineral matter, chlorine, sulphates, arsenic, etc. Yet, as far as I could ascertain, no special precautions seem to be taken in the case of cotton to guard against

[a] "Zeitschrift für angewandte Chemie," 1905, p. 11.

[b] "Zeitschrift f. d. ges. Schiess u. Sprengstoffwesen," 1906, p. 225.

[c] British patent, No. 320, of 1862.

[d] Id., No. 1102, of 1865.

[e] Id., No. 1345, of 1867.

[f] Id., No. 3115, of 1868.

impurities. As a matter of fact, uncarded cotton waste as used for gun cotton generally contains a quantity of strings, wicks, colored threads, india rubber, or elastic cords, and similar leavings, showing the origin of the waste, and no amount of hand picking can free the cotton absolutely from such impurities. I have further found in cotton supplied by manufacturers of the best repute a large amount of chlorine, sulphate of lime, and sulphides, besides organic and mineral dust, which gives the cotton quite a gray appearance.

Is it not also strange that it never occurred to anybody—at least as far as I know—to ascertain whether the impurities in the cotton, brought about by forcible treatment with bleaching agents and acids, are responsible for a great deal of the instability of certain finished gun cotton and smokeless powders? I am convinced that this is the case.

Nobody seems to have given it a thought that such a complex compound as cellulose in the shape of cotton must vary to an enormous extent, both in its physical and its chemical structure, and thereby also the nitrocellulose made from it.

Let us examine the possible changes. In the first instance we have the cotton itself, which may be in any stage of ripeness.

The investigations of Leo Vignon[a] on the formation of oxycelluloses and hydrocelluloses, and the behavior of their nitro compounds, show plainly how cotton and cotton waste may, by the nature of the treatment they undergo, be partly transformed into oxycellulose, which gives an unstable nitro compound, and into hydrocellulose, which has a different rate of nitration than ordinary cellulose.

I have repeatedly stated on previous occasions that in my opinion the process of nitration with a mixture of sulphuric and nitric acids results, in the first instance, in an attack on the cotton by the sulphuric acid similar to that in the manufacture of vegetable parchment, and that the sulphuric acid is gradually displaced by the nitric acid penetrating the fiber.

It seems a fact that the more oxycellulose is formed in the cotton before nitration, the more unstable are the compounds formed in the nitrocellulose. Other impurities in the cotton are all the more likely to endanger the stability of nitrocellulose, as their nature is always unknown, and varies from sweepings to india rubber elastics, while almost all are sure to produce unstable compounds.

How far the nature and origin of the acids may have an influence upon the ultimate product has still to be investigated.

I do not think that differences in apparatus used for the manufacture of nitro-cellulose have much to do with its stability. I have strong reasons for not recommending iron vessels for stabilization in

[a] Comptes rendus, June 6, 1898, September 10 and 17, 1900.

the first instance. I believe that if one must use nitrocellulose, and if, as seems to be the case, cotton is the best material for making it, one ought to use the natural cotton only, and not common yarn, and less still waste, which have both undergone so much forcible mechanical and chemical treatment as to completely alter the character of the cellulose and introduce elements of uncertainty and danger. These should be avoided by the use of ripe raw cotton, which, of course, would have to undergo suitable treatment to eliminate fat, husks, and other impurities, but would not necessitate the whole bleaching operation with its attending defects.

Formerly the mixture for gun cotton consisted of 1 part of 1.500 nitric acid and 3 parts of 1.840 sulphuric acid, and each charge was revivified by taking away one-quarter of the waste acid and adding a mixture rich in nitric acid, so as to obtain about the original composition. The following table shows the result of revivifying the waste acid ten times in a series of operations made in 1886 by Doctor Abelli and the author:

Number.	Composition of nitrating mixture (proportion 1:40).			Temperature of nitration.	Yield.	N.	Soluble.	Composition of waste acid.		
	H_2SO_4.	HNO_3.	H_2O.					H_2SO_4.	HNO_3.	H_2O.
				Degrees.	*Per ct.*	*Per ct.*	*Per ct.*			
1	72.82	24.37	2.81	20	146.25	13.32	3.60	75.15	19.00	5.85
2	71.82	23.00	5.18	10	167.50	13.34	2.10	76.00	18.40	5.60
3	72.45	22.52	5.03	14	169.00	13.39	7.20	73.40	19.10	7.73
4	70.21	23.05	6.74	10	165.75	13.49	2.93	71.40	20.22	8.38
5	68.77	25.97	7.26	12	175.00	13.38	2.88	71.06	20.51	8.43
6	69.47	23.40	7.32	10	166.25	13.08	2.26	71.72	19.43	8.85
7	70.00	22.34	7.66	10	165.00	13.40	4.00	71.71	18.82	9.47
8	70.00	21.85	8.85	9	152.50	13.30	4.80	70.70	19.35	9.95
9	69.18	22.58	8.24	6	167.50	13.22	1.60	71.00	19.13	9.87
10	69.40	22.00	8.60	9	152.50	13.21	3.46	70.00	19.00	11.00

The original mixture consisted of 1 part of nitric acid to 3 parts of sulphuric acid, both of over 97 per cent monohydrate. Three parts of waste acid were revivified with 1 part of fresh acids.

It will be seen that the percentage of nitrogen contained in the nitrocellulose reaches a maximum when the percentage of water in the acid mixture is about 9 per cent, and not, as might be supposed, in the stronger acid.

The majority of factories prepare the nitrating mixture by giving special consideration to the percentage of water in the first instance, because by varying this nitrocellulose of widely different properties can be obtained. I have often said that by varying the concentration of the acids, their temperature, and the time of nitration one has three factors, each of which can to a certain extent influence every property of the nitrocellulose obtained. It is the custom in a major-

ity of factories to produce soluble nitrocellulose by taking equal parts of nitric acid of 75 per cent monohydrate and sulphuric acid of 96 per cent monohydrate and nitrating the cotton at a temperature of 40° C. This nitrating acid therefore contains 14.5 per cent of water. Yet by merely altering the proportions of acid it is quite possible to make very good soluble nitrocellulose in the cold, and some modern factories make it in this way. It seems to be very difficult, if not impossible, to obtain good and stable completely insoluble nitrocellulose from wood pulp.

It is now recognized on all sides that there are no definite stages of nitration in nitrocellulose, but that the change in composition goes on without a break, if the conditions are suitable. The manufacturer of gun cotton and nitrocellulose is face to face with great difficulties. Almost everything he does tends to act detrimentally. From the nitration his nitrocellulose contains a number of lower nitro compounds, nitrated oxycellulose and hydrocellulose, nitrosaccharoses, etc., which he has to get rid of. The usual way to do this is to boil the nitro cotton for a long time. It is not quite clear why one should keep on boiling the long and closed-up fibers of unpulped gun cotton for, say, fifty hours, as is done in some factories. One would imagine that if after a preliminary washing or boiling the gun cotton were pulped and then boiled this could be done much quicker. As a matter of fact, I have found that by heating the gun cotton whilst pulping the increase in stability is very much accelerated, and several factories use the method with advantage. In France they boil for one hundred hours, and I have quite lately seen nitrocellulose that was boiled for two hundred hours without, however, being much the better for it. It must, however, be mentioned that the Waltham Abbey gun cotton as at present made is a very stable and good gun cotton, as judged both by the iodide test and by the destructive test, of which more will be said later on. This is due, in the first instance, to an investigation carried out by Doctor Robertson. He showed that the former method of giving short boilings of two hours and following them up with long boilings of eight and twelve hours was erroneous, and that two long boilings of twelve hours each would liberate acid from the nitrocellulose, giving an acid water which hydrolizes all the impurities without attacking the gun cotton itself, and that subsequent short washings are useful in eliminating the products of hydrolysis. Having had frequent occasion to put Doctor Robertson's principles to a practical test, I consider it to be one of the most useful pieces of work accomplished since the invention of gun cotton.

Messrs. Selwig and Lange, of Braunschweig, have invented the so-called "nitrating centrifugal machine," wherein the cotton is dipped and allowed to stand for the requisite time, and, the nitration being

complete, the centrifugal is set in motion and the acid wrung out. In other words, the removal of the nitrocotton and nitrating acids from the pots into the centrifugal machines is avoided. I am perhaps an heretic, but I have never been able to see the advantage of these nitrating centrifugal machines. They cost a great deal of money; they are liable to get out of order; one can only nitrate about 8 kilograms of cotton in each, and with a nitrating period of, say, half an hour, one can at the best make 10 charges a day in each; further, if the nitrating time is an hour, the number of nitrations is about 7 only. This means that for a fairly large production one requires a large number of centrifugals, and it is easy to calculate what this would mean in an artificial silk factory producing, say, 3 tons of nitrocellulose per day. The quantity of acid used for nitration must be greater, because the space between the basket containing the cotton and the jacket of the machine has to be filled up with acid, and similarly there are a good many other disadvantages. There is no difficulty in arranging pots or basins in such a way that the fumes arising from them are led away by means of an earthenware fan into an absorbing tower, just as is done in nitrating centrifugals and discharging these nitrating vessels into a wringing machine without its being necessary to expose the workmen to fumes or spilt acid. Such factories have been working very many years and give every satisfaction.

Since there is an excess of waste acid produced in revivification, this waste acid is sometimes denitrated in the same way as the acid from nitroglycerin manufacture, but may more advantageously be used in manufacturing fresh nitric acid, because in this case the nitric acid contained in the waste acid is recovered as pure monohydrate.

Revivification is nowadays very frequently carried out with sulphuric acid containing 20 per cent of sulphuric anhydride (oleum).

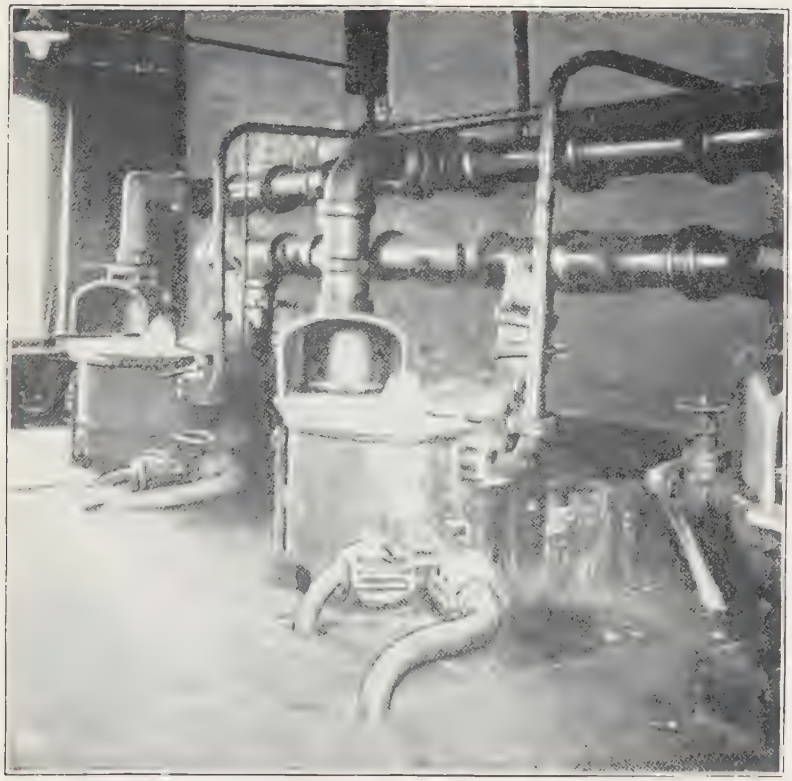
When the gun cotton is pulped and finished it is frequently packed and pressed into boxes. Gun cotton can become moldy on the outside through fungi and, according to v. Förster, have its structure destroyed;[a] and v. Förster found this was promoted by paper in the cases, whilst Malenkowicz[b] showed this to be due to moisture acting on the wood of the boxes. It is very important to select proper packing material on account of the possibility of detrimentally influencing the stability.

A new process for the nitration of cotton is due to Messrs. James Milne Thomson and William Thomson, of Waltham Abbey,[c] and it has already been introduced in some factories. An earthenware funnel-shaped vessel can be connected at its stem by means of cocks,

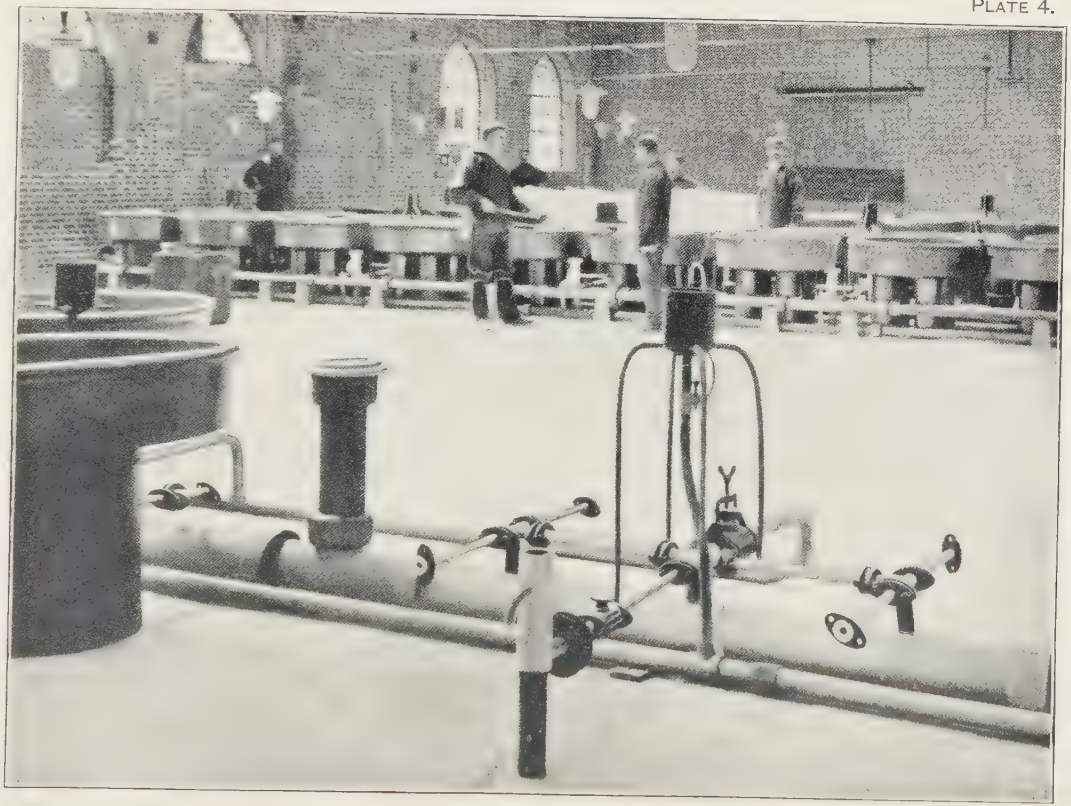
[a] Max v. Förster, "Versuche mit comprimirter Schiessbaumwolle," Berlin, 1883, p. 11.

[b] "Mittheilungen über Gegenstände des Artilleriewesens," 1907, p. 599.

[c] British patent No. 8278, of 1903.



NITRATING CENTRIFUGALS.



NITRATION OF COTTON (THOMSON'S PATENT DISPLACEMENT PROCESS).

either with a pipe supplying fresh acid or with a discharge pipe. An earthenware grating closes the opening of the stem, the new acid is introduced, the cotton dipped in it in the usual way, and then segments made of perforated earthenware plates are laid on top so as to immerse the cotton completely. A small vessel with four outlets is now laid on top, and a Segner wheel distributes water evenly into it, and this is so regulated as to flow out quite slowly and lay itself on the top of the acid without disturbing the latter. This layer of water retains all fumes that may arise from the acid, so that the air in the room is quite good. When nitration is finished water is again allowed to run in, but at the same time connection is made with the outlet pipe, and, the flow of the water being carefully regulated, it gradually displaces the acid. Finally the nitrocotton can be given a preliminary washing.

This process gives very good results, and is very convenient for making gun cotton as required for the British Government, which contains a fairly large percentage of soluble nitrocellulose. As yet there are hardly sufficient data available to decide whether the displacement process will give equally good results for gun cotton with a small percentage of soluble, or, what is far more important for smokeless powder, whether it will enable a soluble nitrocellulose with definite properties to be made, which, as is known, is always a somewhat difficult matter.

It was somewhat of a surprise when Arthur Hough, of New York,[a] announced that he could nitrate starch so as to contain at least 16 per cent of nitrogen. You will remember that Hoitsema [b] has already studied the possibility of producing higher cellulose nitrates than hexanitrocellulose by keeping up the strength of the acid with phosphoric anhydride. Hough seems to have found the practical solution. This nitro-starch has been utilized in the manufacture of smokeless powders, and I understand that it is used to a certain extent in the United States Army.

III.

In the year 1580 Michel Eyquem de Montaigne, in his "Essais," wrote with reference to gunpowder: "Except to astonish the ears, to which by now everybody is accustomed, I believe this is a weapon of very little effect, and I hope that we shall one day give up its use." [c] Would anybody have dared to repeat such a thought thirty years ago? Yet it has come true.

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[a] British patent No. 12627, of 1904.

[b] "Zeitschrift für angewandte Chemie," 1898, p. 273.

[c] "Sauf l'étonnement des aureilles, à quoy désormais chascun est apprivoisé, je crois que c'est une arme de fort peu d'effect et espère que nous en quittons un jour l'usage."

About the year 1410 we find that quaint treatise on gunpowder called "Feuerwerksbuch," said to have been written by a master gunner, Abraham von Memmingen. It contains the famous history of how Berthold Schwarz tried to make a gold paint and invented gunpowder and guns instead. This book was lent to other master gunners, who severally copied and enlarged it, until in 1534 it was printed in Frankfort on the Main under the title, "Büchsenmeysterei." In this printed edition we find a prescription, "how to shoot out of a gun as far with water as with gunpowder." Take 6 parts of nitric acid, 2 parts of sulphuric acid, 3 parts of liquid ammonia, and 2 parts of "oleum benedictum" (crude tar oil), and charge the gun to a tenth part of its bore. It further advises quaintly, "Light it quickly, so as to get away in time. See that the gun is very strong. With an ordinary gun you can shoot 3,000 paces with this water, but it is splendid." This is the first evidence of a nitrated organic substance having been used as a propellant.

I have already alluded to the history of the invention of gun cotton, but one reference remains to be given, showing how early the use of gun cotton in rifles was thought of. It is known that Schönbein reported on his gun cotton on March 11, 1846, and on May 27, 1846, he made experiments with rifles. Professor Otto, of Brunswick, had, independently of Schönbein, also made gun cotton, and published his results on October 5, 1846. He also tried gun cotton in a rifle, and Doctor Hartig published a pamphlet in 1847 at Brunswick, under the title "Untersuchungen über den Bestand und die Wirkungen der explosiven Baumwolle" (Experiments on the Condition and Effects of Explosive Cotton), and therein he makes a statement, which has since attained great importance. He says that the effect which acetic ether has on "the shooting fiber" is very remarkable. He has found that if he makes a stiff, clear jelly with this ether from the shooting fiber, it does not alter its chemical state, and if put in a thin layer on a plate of glass, a snow-white residue is left after the ether has evaporated. If this residue is put into dilute alcohol and then dried it will have in every respect the same properties as the shooting fiber. He mentions already that probably on account of the altered state of aggregation there is a considerable diminution of the explosive force.

Nothing was heard of a real powder made of nitrocellulose for a very long time. It is true that in 1847 the Commission de Pyroxyle, which was appointed in France, "experimented with it in every form, as wadding, spun, twisted, woven, reduced to powder by the action of paper makers' cylinders, felted together by means of dextrine, finally granulated like cannon powder,"[a] but it was too violent for

[a] "Note sur la pyroxyline ou coton-poudre," par M. Susane, Mémoires de l'Académie Impériale de Metz, 1855.

use in guns and rifles. Baron von Lenck, in Austria, made gun charges from fibrous gun cotton, and we know that they were not a success. In 1865 Capt. Eduard Schultze, of Berlin, published a pamphlet on his "new chemical gunpowder," in which he gave the first indication of his powder, but more words than details. At the same time, however, a number of German journals published some particulars of its manufacture. Very soon after Schultze used finely pulped nitrocellulose, and made powder grains by agglomeration with water in drums. It is also remarkable that in 1865 Abel[a] patented the production of grains of gun cotton by placing a mixture of gun cotton with water and a little gum arabic in a pan, and giving it a shaking motion, whereby the gun cotton was formed into grains. He also proposed to mix soluble and insoluble gun cotton, and to make the soluble gun cotton serve as a binding material by treatment with wood spirit, alcohol, ether, or mixtures of these liquids. It is further interesting that Doctor Kellner, of Woolwich, is mentioned in a German book which appeared in 1866[b] to have been the first to succeed in making a granular smokeless powder. Neither Abel nor Kellner seem to have continued at the gelatinization of nitrocellulose.

The author well remembers, however, a firm in Marchegg, near Vienna, which existed under the name of Volkmann's k.k. priv. Collodinfabriks Gesellschaft H. Pernice & Co. They originally bought the patent for the Schultze powder, and made it under the name of nitroxylin. From 1872 to 1875 they made a powder called collodin, the invention of Friedrich Volkmann, which was patented under date November 8, 1870, and May 31, 1871. After three years of existence the Austrian Government ordered the works to be closed, because they claimed that this explosive was infringing their gunpowder monoply.

Volkmann cut up alder wood into small grains of the size of black powder, boiled, and washed, then bleached them, and after final boiling nitrated them in a mixture of nitric and sulphuric acid. Thus far the treatment was that usually given to cotton waste. The finished grains were soaked in a solution of potassium nitrate, or of potassium nitrate and barium nitrate, and, after drying, treated with a mixture of 5 volumes of ether to 1 volume of alcohol. The solvent was allowed to penetrate the grains completely, and the more the substance was dissolved the more the volume decreased. On taking the powder out of the solvent it had the appearance of a mush, which, after twelve hours' drying at 30° C., was converted into a dough, a pasty, pliable substance, from which any shape could be obtained by molding and pressing. Volkmann seems to have known everything about a smokeless powder.

[a] British patent No. 1102, of 1865.

[b] "Buch der Erfindungen," Leipsic, 1866, chapter on gunpowder and arms.

In 1882 Mr. Walter F. Reid patented [a] the agglomeration of nitrocellulose into grains and moistening them with ether alcohol for the purpose of hardening the grains. I had the advantage of seeing this manufacture and some experiments with this powder in 1883, in which year also Oscar Wolff and Max von Förster published and patented [b] the method of coating small cubes of gun cotton with a solvent for the purpose of keeping them permanently moist. Mr. Reid's powder is manufactured under the name of E. C. powder, and is still a favorite sporting powder, but, being what is now called a bulk powder, namely, a powder of very loose structure and low volumetric density, it was too violent in its effects for military rifles, while for sporting rifles it was just the right thing. I would again mention here that in the beginning of 1886 I suggested to Professor Hebler, the well-known Swiss pioneer of the small-bore rifle, the use of a piece of blasting gelatin as a charge for a rifle cartridge,[c] but that the very idea frightened him, although he wished to have a pellet of compressed gun cotton from me for the purpose. Vieille in 1886 [d] thoroughly gelatinized nitrocellulose and made sheets of it, which he cut up in strips or small lozenge-like squares. This was the first military smokeless powder. It has been said that Vieille made his discovery while trying to make a bulk powder similar to E. C. powder, but I have it from him that his invention was the outcome of prolonged study and experiment.

This impartial survey shows that while the merit of making the first powder-like material from a nitro compound belongs to Hartig, and while Schultze made the first commercial powder, yet the invention of a gelatinized powder in the modern sense must be attributed to Friedrich Volkmann, although, independently of him, Reid rediscovered, twelve years later, a hardened sporting powder, and Vieille, sixteen years later, a thoroughly gelatinized military powder.

Nitroglycerin-nitrocellulose powder was invented by Alfred Nobel in 1888,[e] who gave it the name of ballistite. The British Government adopted a powder which contained insoluble gun cotton with nitroglycerin and vaseline, the whole being dissolved in acetone.[f] Ballistite is the service powder in Italy and is much used for large guns. Aniline is now added, and it is claimed both for vaseline, aniline, and diphenylamine that they exert a great stabilizing influence on the powder.

[a] British patent No. 619, of 1882.

[b] Id., No. 3866, of 1883.

[c] Journal of the Society of Chemical Industry, 1894, p. 575.

[d] Mémorial des Poudres et Salpêtres, 1890, p. 9.

[e] British patent No. 1471, of 1888.

[f] Id., No. 5614, of 1889.

There is no need for me to detail the manufacture of powders. Nitrocellulose powders are made from dry nitrocellulose, in a mixing machine, using a solvent (generally ether alcohol or ether acetone). In many factories the nitrocellulose is made anhydrous by soaking it in alcohol, and then squeezing it out in a press. Some think that the quality of the powder is affected by this method. Some have found a loss of substance up to 5 per cent to take place with certain nitrocottons. The mixture is then rolled under a pair of heavy rolls into sheets of the required thickness, cutting them up into squares, and afterwards drying these. In some services ribbons are used instead of grains, and in others threads or tubes are made of such powder and cut into sticks of the length required for the charge. In Germany camphor was formerly added to the powder while kneading it. Some countries leave a certain amount of the solvent in the powder, and formerly in France a little amyl alcohol was added, while now diphenylamine has been adopted; this was already used in 1889 in Germany for C/89 powder made by the Cologne-Rottweil factory.

Ballistite is made in a different way. Soluble nitrocellulose in the shape of a fine powder is suspended in fifteen times its own bulk of water and nitroglycerin added, the mixture being stirred by means of compressed air. This causes the nitroglycerin to dissolve up the nitrocellulose, the water acting as a carrier only. The paste resulting in this way is then brought under steam-heated rolls, weighted to exert a pressure of 100 atmospheres, to thoroughly incorporate it, and then mixed by rolling the sheets over and over until they are quite satisfactory. The sheets so obtained are then cut up into flakes, cubes, strips, etc., as required.

You will readily understand that every weapon may, and generally does, require a different powder in order to give the desired velocity and not to exceed the permissible limits of pressure. It is obvious that it would be very easy to alter the composition in every case, but as a matter of course such an expedient would be quite undesirable alike from a manufacturing and from a service point of view. Hence already in the days of black powder it has been the custom to vary the shape and size of the powder. We thus have ribbons in France, strings in Great Britain, flakes and tubes in Germany, cords of square section in Italy, short multiperforated cylinders in the United States, cubes from ballistite, spiral sporting powder in Germany, the poudre peigne (spiral powder with comb-shaped incisions) of French inventors, etc. Further, these powders may then be made in various lengths, breadths, or thicknesses, and with various kinds of holes, incisions, etc. It is quite impossible to generalize and to say that a particular form is good or bad, because it probably does suit a special weapon. It is a fact that up to a certain size round

grains are most likely to give good combustion, and that cord or tube comes next; on the other hand, a flat ribbon is likely to burn more uniformly, although, again, a variation in the rate of combustion at different intervals of time may just be what is wanted.

The conviction has grown of late that in addition to being smokeless a powder should also be flameless, so as not to disclose the position of an attacking force.

The military powders suffer, in the first instance, from irregular shooting. In the case of sporting powder, it is necessary to carry out shooting tests with every small batch, because the reputation of a firm depends on keeping powder out of the market which is in the slightest degree deficient. Careful blending has to be resorted to in order to obtain absolutely uniform results throughout.

Of other difficulties in manufacture I will mention only a few. The treatment of a powder under rolls is to a certain extent guided by rule of thumb. It is all very well to look through the paste, the sheet may appear quite transparent to a good and experienced eye, yet small nodules of nitrocellulose may have escaped solution for a long time. The constant crackling heard when rolling thin sheets plainly points to such isolated and undissolved fibers. Incorporating in a kneading machine does not improve matters. Pressing powder out of a die gives very good results with small diameters, but with larger diameters very much depends upon the shape of and the wear on the nozzle, its position among several others or relatively to the die, and on whether the outer skin will contain air bubbles or be cracked. If too much solvent is taken, or the proportions of a composite solvent are not quite suitable, the density and uniformity of the powder will suffer. One of the greatest difficulties lies in the proper drying of powder. The smaller sizes of sticks, ribbons, tubes, etc., are easier to deal with. The larger and thicker ones, however, sometimes require months to dry properly. With some powders this defect is to a certain extent avoided by leaving some of the solvent behind, but then, of course, we have on the one hand the difficulty of not knowing exactly when the correct amount of solvent is present, and, on the other hand, a certain amount of risk in that the powder would in course of time undergo changes by gradual evaporation of the solvent.

Sporting powders are of two kinds, the so-called "bulk" powders, consisting of loose granules, coated or hardened by means of a solvent, and the so-called "condensed" powders, gelatinized throughout, and made in practically the same way as military flake powders.[a] The former are supposed to just fill a cartridge used in the old black-

[a] The micro-photographs reproduced on plates 5 and 6 were kindly prepared by Mr. Henry de Mosenthal.

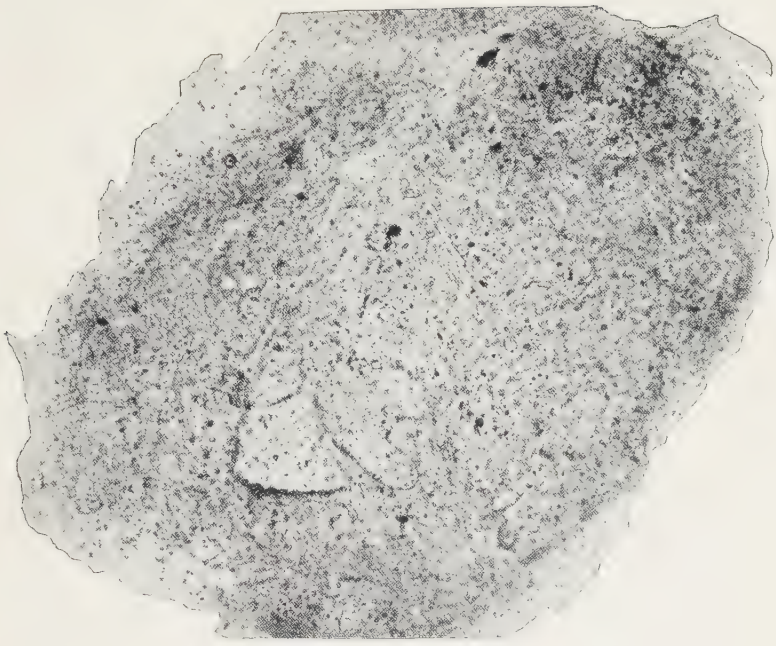


FIG. 1.—SMOKELESS BULK POWDER SEEN UNDER THE MICROSCOPE IN ORDINARY LIGHT.

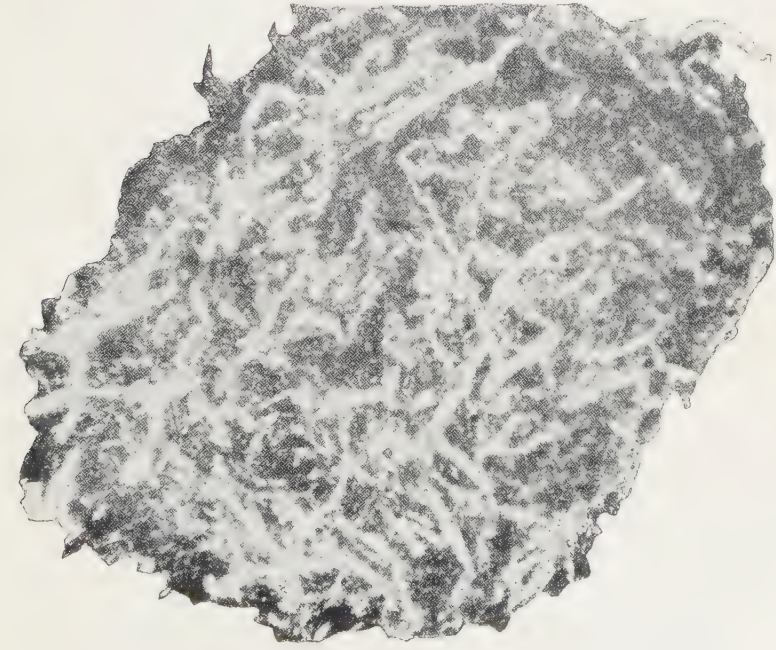


FIG. 2.—SMOKELESS BULK POWDER SEEN UNDER THE MICROSCOPE IN POLARIZED LIGHT.

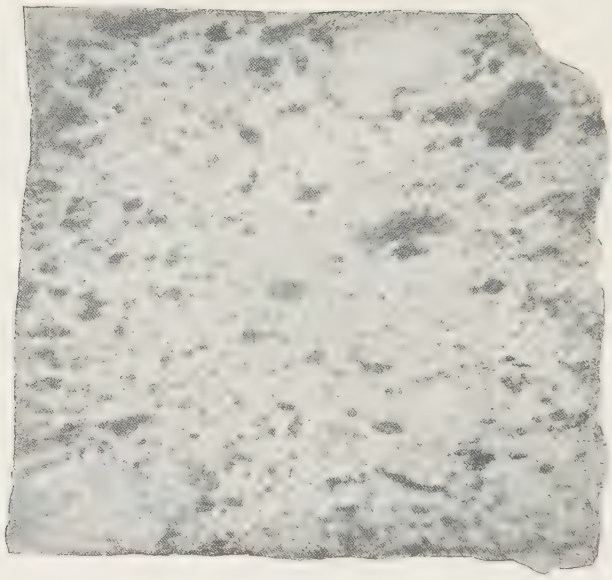


FIG. 1.—SMOKELESS FLAKE POWDER SEEN UNDER THE MICROSCOPE IN ORDINARY LIGHT.

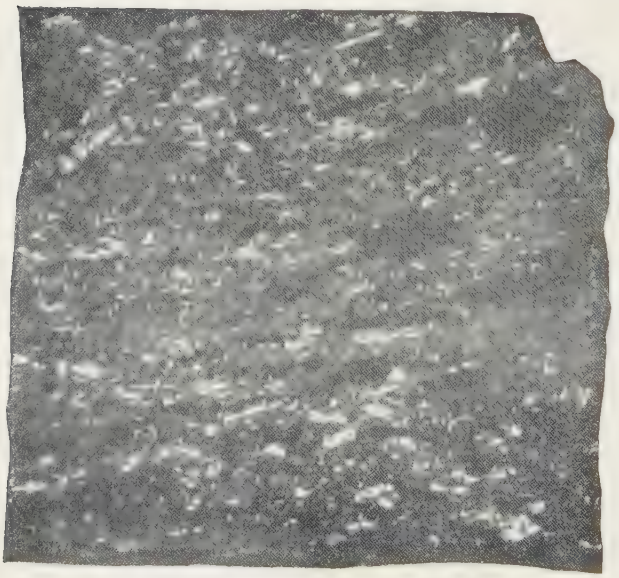


FIG. 2.—SMOKELESS FLAKE POWDER SEEN UNDER THE MICROSCOPE IN POLARIZED LIGHT.

powder gun; the latter are made for modern weapons. The usual "bulk" powders are composed of soluble nitrocotton mixed with potassium or barium nitrate, and generally worked up in an incorporating mill or drum. The mixture is then either sprinkled with water in a rotating drum, so as to form grains, or extended on a shaking table making short and rapid oscillations. Alternatively it may be put into an hydraulic press and then broken into grains, the solvent being in every case sprinkled over when the grains are already formed.

The "condensed" powders are usually made by rolling the "paste" into very thin sheets (0.1 millimeter and less), which are then cut into small flakes to obtain the requisite rapidity of combustion. Such powders are dried fairly quickly, and they may sometimes even be boiled in water to promote elimination of the solvent.

Since 1800, when Howard invented fulminate of mercury, and since 1815, when Joseph Egg made the first cap, but little progress has been made in the manufacture of these articles. It is still the usual cap and the usual detonator, the only difference being that potassium chlorate enters partly into the composition of detonators, whilst for smokeless powders a hotter flame is found essential, and is obtained by adding a combustible substance. Aluminum powder, either mixed with the fulminate or pressed in a layer on top of it, has been successfully employed.[a] The Rheinisch-Westfälische Gesellschaft of Troisdorf make now detonators of tetranitromethylaniline (called tetryl).[b] It is said that quite half of all the detonators at present manufactured in Germany are made with trinitrotoluene.

The manufacture of fulminate of mercury is performed in almost the same way as that described fifty years ago.

The increasing demand for ammonium nitrate safety explosives has resulted in the use of greater quantities of powerful detonators. For the same reason great progress has been made with electric detonators. Formerly high-tension fuses fired by frictional electric machines were almost solely used, and Breguets were the only low-tension fuses employed in mines. Nowadays the tendency is to use low-tension fuses and magneto-firing apparatus, thus greatly reducing the risk of firing the pit gases.

Bickford's invention still holds the field as regards safety fuses. I have explained in my first lecture wherein the few improvements consist that were made on safety fuses. It is curious that all attempts to make a safety fuse with a core of smokeless powder or some other nitro compound have so far been unsatisfactory. It seems impossible to insure uninterrupted burning. Of late, rapid-burning fuses

[a] British patent No. 23366, of 1904.
[b] Id. No. 13340, of 1905.

were introduced, some being fired in groups by means of pistols and other central-firing arrangements. General Lauer and Mr. Tirmann introduced friction fuses, which are fired by means of wires from a distance, and are extensively used chiefly in Austrian coal mines. Girard made "cordeaux détonants" by filling lead tubes with nitrohydrocellulose and then drawing them out to the diameter of an ordinary safety fuse. In 1906 these fuses were filled with melinite, and now trinitrotoluene is also used, which permits the employment of lead tubes instead of the costly tin tubes indispensable with a picric acid explosive.[a] The most perfect fuse of this kind is, however, the instantaneous fuse invented by General Hess and introduced into the Austro-Hungarian service. Originally it consisted of a mercuric fulminate core on four threads. In 1903 Hess "phlegmatized" the fulminate [b] by the addition of 20 per cent of hard paraffin, but a number of such fuses, tied together by knots, can be detonated by a common detonator, thus replacing electric shot firing and dispensing with a detonator in each bore hole. The fuse can be cut, hammered, squeezed, etc., without danger.

The more industry progressed all over the world, the greater the coal consumption became, and the more frequently occurred those appalling mine disasters which from time to time convulse public feeling. The British Government was the first to nominate a fire-damp commission. Then followed commissions in Prussia, France, Saxony, and Austria, but not one of them tried a safety explosive before September, 1885. The Prussian Government, however, had built a testing station and trial gallery at Neunkirchen, in the beginning of September, 1885, under the direction of Mr. Margraf. In September, 1887, a carbonite consisting of saltpeter, cellulose, nitroglycerin, and sulphureted oil was found to be absolutely safe. In 1886 Margraf tested securite against carbonite, and this also was found safe. In April, 1887, roburite and kinetite were tried, and in August, 1887, soda dynamite. Thus carbonite was really the first safety explosive.

It is necessary to distinguish between explosives which are safe in manipulation (handhabungssicher) and such that are safe in fire damp (wettersicher). The latter only are called safety explosives in this country.

The obvious question is, What makes an explosive safe in fire damp? I confess that, having most carefully examined the views of those most competent to given an opinion, I fail to find a definite answer. At one time the Prussian commission stated that the more rapid the explosion the safer the explosive, and some color is lent to

[a] Artilleristische Monatshefte, August, 1908.

[b] "Mittheilungen über Gegenstände des Artillerie und Geniewesens," 1907, p. 115.

this theory by the fact that fulminate of mercury does not ordinarily ignite fire damp, whilst black powder always does. The theory is, however, controverted by certain black-powder mixtures, foremost among which is bobbinite, which is safe up to a certain point, and by nitroglycerin and blasting gelatin, which are not.

The French Government commission stated that an explosive whose temperature of explosion was below 1,500° C. could be licensed for use in fiery mines. Curiously enough carbonite, so far the safest of all, and several others, which are licensed for such use, have a temperature of explosion considerably higher than 1,500° C.

Mr. Bichel, in conjunction with his collaborator, Doctor Mettegang, says that the velocity of detonation, the maximum temperature of the products of combustion, the length and the duration of the flame of an explosive all influence the safety of an explosive adversely.[a] He considers, and in the author's opinion very justly, the nature of the products of combustion to be all important, whether they consist of solid particles which remain incandescent for a considerable time, or of large quantities of combustible gases shot forward with great force. In this way he corroborates early attempts to photograph the flame of an explosion made by Schoeneweg, the inventor of securite, and by Siersch, of Pozsony. The velocity of detonation can not, however, be considered to be a determining factor under all circumstances. Certain nitroglycerin explosives, amongst which we may also include carbonite, explode much more rapidly than, say, bobbinite, and yet show themselves to be much safer when tested. I myself have found that up to a certain point the addition of picric acid gave increased safety on test.

It will be remembered that the British commission found a water jacket round the charge very efficient. Sodium carbonate, magnesium sulphate, and other substances were tried, either separately in front of the explosive or as ingredients. More prominence was then given to the French recommendations, and the notion became prevalent that the addition to the explosive must be a flame-cooling agent in the shape of water vapor or some other heat-absorbing gas. Thus permanganate, bichromate oxalates, and other salts were used, and of late common salt has sprung into favor.

The only definite result obtained so far is that ammonium nitrate is absolutely safe in all quantities, and that cellulose and similar substances in nitroglycerin compositions—e. g., rye flour in carbonites or wood pulp in other explosives—renders them highly inert in fire-damp mixtures. Ammonium nitrate can not, however, be used by itself, although Lobry de Bruyn succeeded in exploding it,[b] and therefore some combustible substance must be added. It simply

[a] Glückauf, 1904, No. 35.

[b] Recueil des travaux chimiques des Pays-Bas, 1891, p. 127.

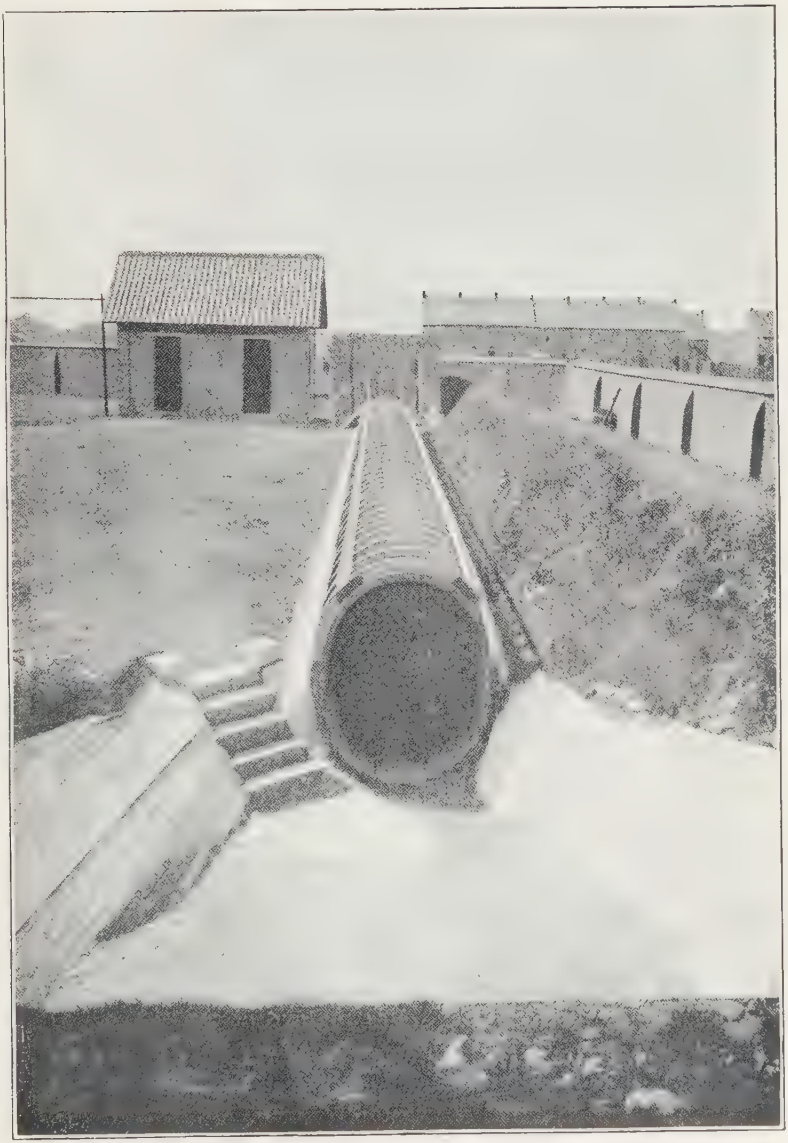
remains to be determined what minimum quantity of such combustible can be added to avoid flames of great length and duration.

The next question is, How can one tell whether an explosive is "safe"? This question is a still more difficult one to answer. The various governments and also certain factories have erected testing stations. These stations generally consist of a long wooden or iron tunnel, round or oval in section. The explosive is shot into a gas mixture. In this country a ballistic pendulum is used to ascertain the quantity of the explosive equal in force to 4 ounces of dynamite No. 1, and this quantity with a stemmed shot is then fired in air containing 15 per cent of coal gas. If the mixture does not fire in 20 shots the explosive is considered a safe one. In most other countries the quantity of the explosive in question is determined which will fire and that which will just not fire a certain pit gas mixture. This gives us what Mr. Watteyne, the well-known Belgian authority, calls the "charge limite" of an explosive. This latter way is certainly the more rational one, since it permits of comparison between different kinds of explosives. Is this method of testing, however, above reproach? I think not, although I know of no better one at present. It has been found that the narrower the bore of the cannon the easier ignition takes place under certain circumstances. The Woolwich circular section gallery, which has a sectional area of 0.36 square meter, is much more sensitive than the elliptical Belgian one, whose sectional area is 2 square meters, and, in fact, even with equal diameters each gallery may be said to have its own ignition temperament, which affects the results. Thus quite recent tests at Frameries in a gallery having a sectional area of 0.28 square meter showed that two safety explosives, whose charge limite was 900 and 450 grams, respectively, fired at 300 and at 75 grams. The gas used also exerts considerable influence on the tests.

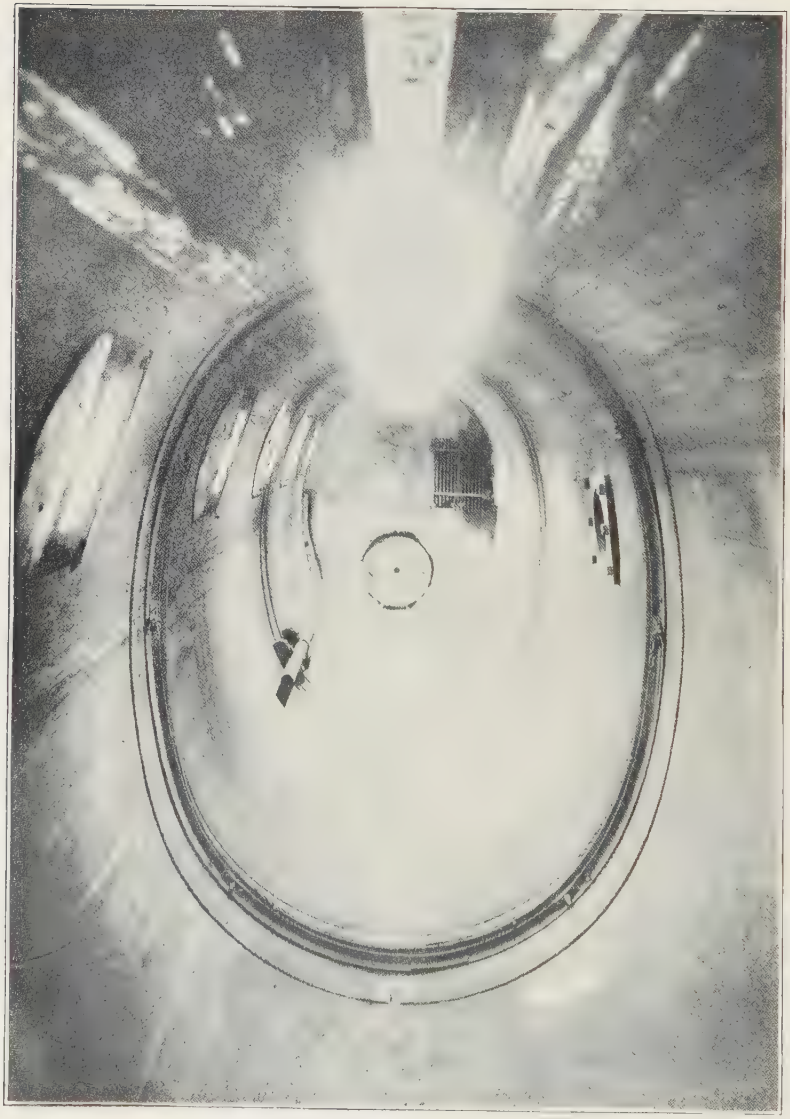
It has been known for a long time that coal dust as well as pit gas is highly explosive. I believe that Engler, when investigating explosions in the charcoal heaps of the Black Forest,[a] was the first to show that mixtures of coal gas and air, so poor in gas as to be noninflammable, were rendered explosive by the addition of some charcoal dust. The Mining Association of Great Britain took the lead, experimentally investigating the influence of coal dust on explosions in mines. An iron shell 7 feet 6 inches in diameter and 1,083 feet long was used to carry out the experiments. So far it has already been ascertained[b] that two zones of stone dust on either side of a zone of coal dust arrested the path of a flame, and that unless the coal-dust zone exceeded 180 feet in length, no explosive force was mani-

[a] Chemische Industrie, 1885, No. 6.

[b] "Coal dust experiments," The Times, September 24, 1908.



TESTING STATION AT FRAMERIES (END VIEW).



TESTING STATION AT FRAMERIES (VIEW OF THE INTERIOR).

fested. Might I submit an old idea, which I base on some patents of mine that have proved highly useful? An absorption tower retains solid particles contained in a gas mixture, and also cools the latter very efficiently, and one of the best methods for absorption has proved to be the production of a fine spray or mist of moisture. It seems quite feasible to utilize certain lengths of tunnel for the construction of inverted absorption towers at intervals, and certainly at every point where a side gallery runs into the main or haulage roads. So much seems certain to me from the study of the results of past investigators that a small addition of coal dust will be found to promote the explosion of poor gas mixtures, and that, therefore, a separation of the dust from the gas will in some cases prevent an explosion.

Lacking definite knowledge as to what renders an explosive safe in fire damp, and how this is to be ascertained, it would be natural to seek a solution in practical results. The sale of an article does not always depend upon its real value, but very frequently on the way it is advertised and pushed, whether it is made in the country of consumption or not, whether it possesses disadvantages that render another less efficient article a preferable one, etc. In spite of this it is not unfair to assume that the statistics showing the quantities of safety explosives actually consumed in a great coal-producing country like Great Britain have a real bearing on the question as to which explosives have given a reasonable amount of safety. The report of the inspectors of explosives for 1907 gives the following highly instructive figures: Out of a total consumption of 7,764,122 pounds, were used, of saxonite, 1,721,193 pounds, or 22.18 per cent, and of bobbinite, 1,063,111 pounds, or 13.69 per cent.

Saxonite contains a large percentage of nitroglycerin. Bobbinite is a black powder mixture.

From the inquiry on bobbinite[a] the following table regarding accidents in coal mines caused by various safety explosives in 1904 and 1905 is calculated:

	Consumption.	Accidents.		Killed.		Injured.	
	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
Bobbinite	13.69	20	17.54	2	8.33	30	18.87
Other permitted explosives	86.31	94	82.46	22	91.67	129	81.13

It will thus be seen that a black powder mixture like bobbinite, which would not be licensed in any other country and be condemned without trial, ranks second in consumption, being used to the extent

[a] Report of the departmental committee on bobbinite, London, 1907.

of 13.7 per cent of the total consumption, while saxonite, a nitroglycerin explosive, ranks first, with 22.18 per cent of the total.

Am I therefore right in saying that we have succeeded in making the use of explosives in coal mines infinitely more safe than before, but that we do not really know why?

IV.

Nitrocellulose has found a greater sphere of use for purposes other than smokeless powder or dynamites. The celluloid industry, introduced by the Brothers Hyatt, and more recently the artificial silk industry, consume enormous quantities. Of celluloid the United States produce about 4,000 tons per annum, Germany 15,000, and the rest of the world about 5,000 tons, of which yearly total of 24,000 tons this country produces about 2 per cent. This necessitates about 14,000 tons of nitrocellulose per annum. Of artificial silk, about 5,000 tons are made annually, though only about 200 tons in England.[a] The amounts used for varnishes like pegamoid, fabrikoid, etc., for making or steeping incandescent gas mantles, for waterproofing solutions, for patent leather (nitrocellulose dissolved in amylacetate, and mixed with aniline black) and for photography are also considerable. The solubility of the nitrocellulose in a definite mixture of ether alcohol to the extent of 2 per cent either way is by no means unimportant, as this may mean 10 per cent more of very expensive solvent. When you consider that one of these factories, which I had occasion to revisit quite recently, makes as much as 3,000 kilograms of silk a day, you will have some idea of the sums involved.

In neither of these cases is the nitrocellulose pulped, but the whole of the fiber is dissolved. I am afraid purification is sometimes not carried as far as it ought to be with due regard to the stability of the finished celluloid. In the case of artificial silk the fact that the nitrocellulose is denitrated seems to indicate that thorough purification is unnecessary, but the silk fiber made from well-stabilized nitrocellulose will be found to possess inherent good properties of its own. The same may be said of varnish, although in this case a slight acidity at certain stages of the process has the advantage of rendering the nitrocellulose more readily soluble.

The manufacture of these nitrocelluloses also varies in other respects. In dealing with such large quantities everything is carried out expeditiously and without much handling. The nitrocellulose for

[a] According to Dr. Richard Schwarz, there are at present in Europe 30 factories making artificial silk, and the world's production in 1907 amounted to 3,300,000 kilograms, of which 1,500,000 were nitrocellulose silk, 1,300,000 "Glanzstoff," and 500,000 viscose silk (Neue Freie Presse, Vienna, January 5, 1909).

artificial silk is not fully dried, but from 12 to 30 per cent of water is allowed to remain in it.

For the sake of completeness mention must be made of the proposed use of explosives for motive power. I well remember having shown me at Vienna, in 1878, an engine to be worked by small charges of dynamite. In order to show the absence of danger the inventor had made the model entirely of wood. Again, quite recently my advice was sought regarding the application of smokeless powder to flying machines. Several patents referring to motors and compressors driven by explosives have been taken out, and one of them quite recently.[a]

An account of progress on explosives would be incomplete without mention of the conditions under which they are manufactured.

The late Col. Sir Vivian Dering Majendie deserves lasting recognition for having created that most excellent explosives act of 1875. The influence of this act, and perhaps almost to the same extent of the annual reports of the British inspectors of explosives on the arrangements and construction of buildings and machinery, the general cleanliness of the operations performed, and the security of workmen against accident can hardly be overrated, and the example set in this country has been followed all over the world.

In arranging buildings due consideration is now paid to the dangers present on account of the nature of the operation and the quantity of materials dealt with. The advent of high explosives has unfortunately made us acquainted with effects of explosions unknown in the old powder days, and in order to counteract these effects the author recently suggested [b] the construction of danger buildings in a special kind of ferro-concrete. The buildings are so designed that pieces of burning débris can not penetrate their roofs, and so bring about their destruction. At the same time the shock of the explosion transmitted from a distance through the ground will not cause the walls to open out. This proposal has been very favorably received by a number of manufacturers, and in several instances has already been adopted. The armoring of such a building forms a Faraday's cage, and renders the whole structure lightning proof. This is of importance, since the regulations governing the erection of lightning conductors have not increased the safety of buildings to any great extent in spite of lightning-rod conferences and investigations. Magazines which were satisfactorily tested on the very day of a thunderstorm have been blown up, and nothing short of a cage, or at least a

[a] British patents, Nos. 961, of 1874; 24742, of 1904; 28376, of 1904; 22425, of 1905.

[b] "Explosions and the Building of Explosives Works," Journal of the Society of Chemical Industry, 1908, No. 13.

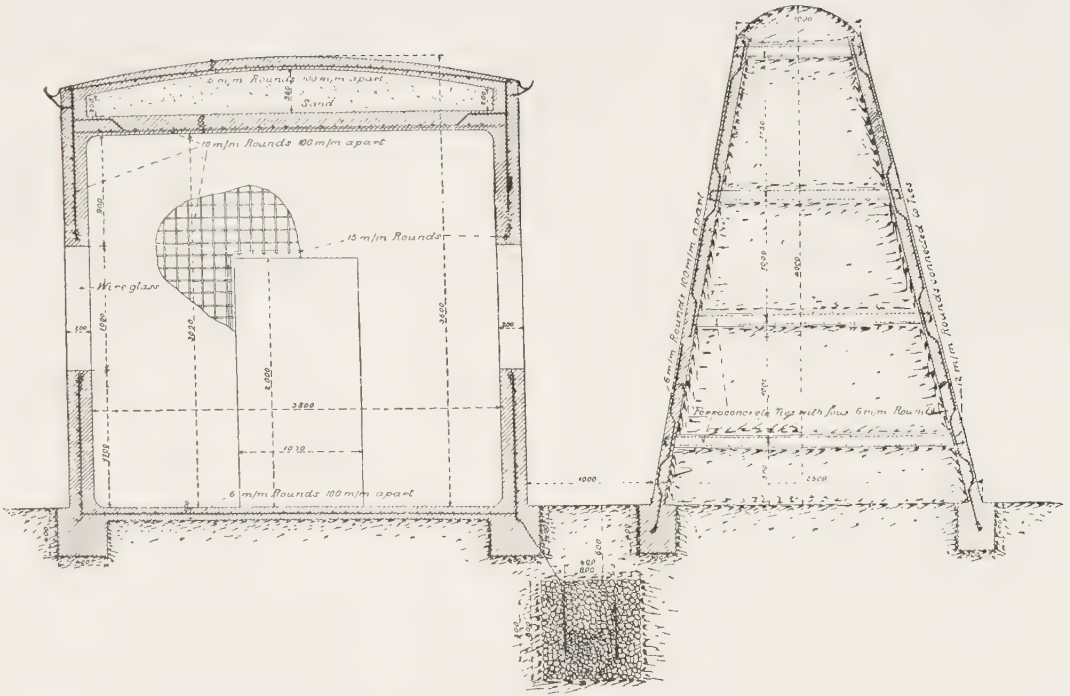
complete system of conducting network over and on the buildings, seems to be efficacious.

Despite all precautions disasters of great magnitude will occur in modern explosives works. This is, no doubt, in the first place, due to the fact that quantities are nowadays made in such works which were not dreamed of thirty years ago. For instance, the works at Modderfontein and Somerset West produce annually over 10,000 tons of dynamite, and several other works run them very close. Such an enormous output requires a very considerable number of buildings, and consequently the chance of damage to life and property is greatly increased. The construction of factories has, on the other hand, proceeded on somewhat orthodox lines, and not always, perhaps, with due regard to subdividing and minimizing risks.

Another reason for such catastrophes is the want of appreciation of certain inherent dangers. The author has always warned manufacturers and users alike that the function of an explosive is to explode, and that although certain compositions are almost insensitive to ordinary impulses, such as blows, friction, etc., yet he never believed that any explosive existed which under favorable conditions and by proper means could not be made to explode. It is true that continental railways carry certain explosives, like ammonium nitrate mixtures, by ordinary goods train, and the author believes this to be an example which might be quite safely followed by British railway companies in the best interests of the public. There is no danger attached to any of these explosives when in the safe custody of a railway van, and when they do not come into contact with dangerous goods.

Yet another warning to manufacturers may not be out of place. Special attention must be paid to prevent any accumulation of dirt in places liable to exposure to heat. In the French powder factory at Saint-Médard the explosion which occurred in 1891 could be clearly traced to gun-cotton dust lodging in the joints and cracks of a wooden workshop.[a] Do factories even now take every precaution to prevent the accumulation of dirt of this kind? The author has reason to doubt it, and a clean-up at a factory which he witnessed a short time ago was quite an eye-opener. He can only warn those concerned that every building where explosive dust can be produced, and every appliance and utensil therein, should be periodically and thoroughly cleansed and overhauled. Imagine a drying tray, covered underneath with canvas, on which gun cotton or powder is dried all the year round, and ask yourselves what the chemical stability of the dust may be after a year's exposure to a temperature of 40° C. (some factories dry at 50° C.), and whether a material dried on such a tray is fairly treated.

[a] Mémorial des Poudres et Salpêtres, 1894, p. 7.



EXPLOSIVES WORKSHOP AND MOUND BUILT IN FERRO-CONCRETE.

Nowadays an explosives factory seems inconceivable without electric light and small motors near buildings or on machines, while even the operation of drying sensitive compositions is performed by electric resistances serving as a perfectly adjustable source of heat.

Modern explosives have, on the other hand, introduced electrical dangers themselves. In the first lecture the possibility of firing a press charge of black powder by static electricity collecting between ebonite press plates was mentioned. Nitrocellulose is electrified by the current of warm air passing over it when drying, and the necessary earthing arrangements were first proposed by Mr. Walter F. Reid, and in many cases especially designed by the author. Mixing machines for blasting gelatine and smokeless powder, especially those provided with reversing gear and belts running in opposite directions, have been known to give long sparks unless properly earthed. This was remedied at Waltham Abbey by saturating the belts with glycerin. The powder itself during manipulation will generate electricity. Ether vapor given off from smokeless powder and mixed with air can be fired with a very small spark, and special care should be taken in preventing its formation.

The manufacture of high explosives seems a simple operation even to experienced chemists, and the danger attending the process appears to be the only difficulty. As a matter of fact, it bristles with difficulties. A good many have already been mentioned, and a few additional and special points are worthy of note.

Glycerin is a uniform, easily purified substance, and its nitric ester, nitroglycerin, although sensitive to a blow, especially when frozen, is a chemically stable explosive, tame and harnessed for the service of man. Most nitro compounds of the aromatic series have very great chemical stability.

Picric acid is a treacherous substance. It is very powerful, but that is its only recommendation. Those who use it may be asphyxiated by the fumes of a prematurely exploding shot; those who are fired at sometimes rejoice when it fails to explode. It requires special mixtures to avoid melting at high temperatures, and it attacks its metal container, forming a dangerous picrate. As an ingredient of other explosives it is useless, since on account of its acid properties it reacts upon the other ingredients. Moreover, it is capable of displacing other acids, such as nitric acid in nitrates, a disagreeable property which some patentees have found out to their cost. With Montaigne, " I hope that we shall one day give up its use."

A more inconvenient material still is nitrocotton. As already stated, cotton is one of the most complex substances known, and for some unexplained reason we have been in the habit of using it after an ill-treatment following upon an undesirable state of cleanliness. At the best, however, we have an almost uncontrollable substance in

nitrocotton. It is in such a loose state of equilibrium that the slightest reaction will upset its balance. No wonder that when nitrocellulose is mixed with another explosive like nitroglycerin to form smokeless powder it becomes less reliable, and acts detrimentally on the nitroglycerin. This is accentuated still more in the presence of another disturbing factor, such as heat or an alkali. It is a fact that any alkali, however weak, will gradually saponify the nitrocellulose, and although dangerous decomposition would rarely set in, a bad heat test may result and cause the nitrocellulose to be destroyed by the authorities. Chalk in water is no exception to this action.

The case is very much aggravated by the action of heat. It is well known that properly purified guncotton has been stored in all climates without giving rise to alarming decomposition, even when the temperature was above the normal. Nitroglycerin and nitrocellulose, both of which will by themselves give a potassium iodide heat test of, say, twenty minutes, may, however, when mixed, not stand more than ten minutes. It is a convenient excuse to say that this is due to an alteration of the physical state, but no proofs have been given for such an assertion, and I should be curious to hear of them.

The amount of nitrous acid required to color the test paper is so small (according to Will[a] it is only 4×10^{-5} milligrams, equivalent to 0.0000016 per cent, or about 1 in 60,000,000 for a sample of 2.5 grams) that whatever its physical state, there would always be enough material exposed on the surface to give off this quantity of gas in regulation time if the explosive were of a low order of stability. There is much more justification for supposing that a chemical reaction goes on between the nitroglycerin and nitrocellulose at the elevated temperature of the heat test (82° C.), the nitrocellulose being first decomposed, and the nitrous gases developed reacting on the nitroglycerin and thus accelerating the decomposition.

We next come to the treatment a powder undergoes during manufacture. Whether passed under steam-heated or high-pressure rolls, whether kneaded for hours in a mixing machine, squeezed from a die with an unnecessary amount of pressure and friction, due to a defect in or bad construction of the die, whether it be dried for weeks and months at temperatures far above the normal, everything tends to destroy the equilibrium of the nitrocellulose. Years ago the author showed that there is a critical point for mixtures, such as blasting gelatine or smokeless powders at or about 45° C., yet during manufacture this temperature is frequently approached and sometimes exceeded.

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[a] Dr. W. Will, "Untersuchungen über die Stabilität von Nitrocellulose 2. Mitteilung. Der Grenzzustand der Nitrocellulose in quantitativer Beziehung." Neubabelsberg, 1902, p. 28.

In some countries the heat test is still carried out at a temperature of 65° C., and if the explosive stands it for, say, thirty minutes, the result is considered satisfactory. Yet how often have we seen this temperature attained during manufacturing operations, and maintained for hours! Is this reasonable?

We will assume now that we have taken every precaution to manufacture an explosive which, as regards purity of its ingredients and as regards care in its preparation, leaves nothing to be desired. We were told everywhere until about ten years ago, and are still told so in this country, that the explosive must be heated to a temperature varying from 65° to 82° C. without developing sufficient nitrous acid fumes within, say, ten minutes to color potassium iodide paper. The vagaries of this test are very amusing. Eleven years ago [a] the author was the first to show how it could be masked and falsified. The potassium iodide paper itself is an uncertain factor. Great precautions must be taken in its preparation, while the thickness of the paper is such a disturbing factor that the papers from one official source give a test nearly double those from another.

Various other tests on similar lines have been proposed to replace the potassium iodide test, but not one of them is a true test of stability. The potassium iodide, or the diphenylamine test, if always carried out under identical conditions, are good enough as a rough check on the manufacture. They do not, however, show whether the material itself is so constituted as to remain stable. This is, perhaps, of small importance in the case of nitroglycerin or an aromatic nitrocompound with their relatively simple structure, but it is all important for nitrocellulose, where the heat test in the opinion of most experts is of little value as a criterion of the finished article. In order to judge of stability, the critical point at which an explosive breaks down must be found, and it is also necessary to determine whether decomposition proceeds regularly or at a dangerous and increasing rate when this point is passed. A number of tests have been proposed to fulfill these conditions. They are all based on the principle that a small quantity of explosive is heated to a temperature which causes decomposition comparatively quickly yet gives sufficient time to differentiate results. In France this temperature was 110° C., but all the modern so-called "destruction" tests are made between 130° and 135° C.

All these tests require a considerable amount of time and constant supervision by a chemist. A rapid and reliable method is to heat the explosive in long glass tubes immersed in a bath of amyl alcohol provided with a reflux condenser, and to note the time that elapses

[a] The Chemical Stability of Nitro-compound Explosives, "Journal of the Society of Chemical Industry," April 30, 1897.

before a distinct coloration in the tube is observed. This method compares very favorably with all others.

As I frequently mentioned, the duration of the heat test is practically halved by a rise in temperature of 5° C., and Will has confirmed this by proving that the volume of gases evolved is doubled at the same time. This is, however, only correct for temperatures above 45° C., the critical point for nitrocellulose. Below 40° C. the durability of an explosive properly prepared with it increases exceedingly rapidly, and it may be safely assumed that under 20° C. its stability is permanently assured.

This contention has been proved in practice. The author does not know of a single authenticated instance of decomposition in an explosive magazine where the temperature has been kept within the permissible limit.

This simple precaution was, however, neglected in a good many instances by both naval and military authorities. It was and still is the practice in men-of-war to arrange the ammunition stores and powder magazines in close proximity to boilers and engines, frequently without any ventilation, whilst at times explosives of all kinds are stored together. Fourteen years ago[a] the author discussed this arrangement, and drew attention to the dangers arising therefrom. A dozen explosions on men-of-war and a disaster like that on the *Jena* occurred before an alarm was raised, and now all navies are hurriedly installing refrigerating apparatus. This is all very well as far as it goes if the machinery does not break down at the critical moment; but can not designers of war ships find another place for ammunition? Why go to the length of all sorts of precautions when it should not be impossible to remove the cause of deterioration altogether?

This misplacing of ammunition stores is only slightly mitigated by the fact that twenty years ago the manufacture of smokeless powders had only just begun, and nobody knew much about them. Worse than this, however, was the action of many governments in at once erecting their own powder works, without any experience in the manufacture of nitrocompounds to go upon, and relying entirely on what private manufacturers cared to show them, and on what they themselves could find out by experiments. Some of their powders made fifteen and twenty years ago are still in service, and are now the objects of suspicion.

It is, nevertheless, not fair to throw the whole of the blame on the explosive charge. How would the priming and detonating compositions used in gun charges and shells behave under unfavorable circumstances? Fulminate of mercury, potassium chlorate, sulphur, antimonypentasulphide, picric acid, and other chemicals are con-

[a] Journal of the Society of Chemical Industry, 1894, p. 583.

tained in such compositions, and it is open to question whether proper tests are always carried out as regards their purity and stability under all conditions.

Fearing the lack of stability in smokeless powders, which in the early days of their manufacture was not without justification, inventors began to look around for so-called "stabilizers," that is to say, additional ingredients, which would neutralize the nitrous acid liberated on decomposition. Some people thought that if a little ether alcohol was left in the powder it would act as a stabilizer, and in order to prevent the rapid escape of the solvent on storage, a little amyl alcohol was added, thus slightly raising the boiling point of the solvent.[a] As a matter of fact, this would merely constitute absorption of the nitrous vapors, but would not prevent their being given off again on heating.

A better plan is the addition of "stabilizers," which would form stable compounds with the nitrous acid; for instance, aniline, which the Nobel factory at Avigliana used in their gun cotton twenty-four years ago, and which both they and the Italian Government employ for service ballistite. Diphenylamine and, it is said, vaseline would act in a similar way. The stable compounds formed from stabilizers, like amidoazobenzol and other aromatic nitro compounds, retain the nitrous acid, and thus transform the reaction into a slow and regular one, which keeps the powder in good condition as long as there is any stabilizer left. The length of time a powder remains in good condition will therefore only depend on the proper constitution and manufacture of the powder.

Stabilizers, like diphenylamine and aniline, will also reveal their presence as soon as the powder goes wrong, since the compounds formed with them by the action of nitrous acid show as spots or stripes of peculiar colors, varying either in shade or intensity as decomposition progresses. Since the French commissioners on the *Jena* accident emphasized this fact, already known in Germany and Italy, everybody speaks of "révélateurs," the addition of an indicator, as being a panacea. As a matter of fact the author considers it only a needlessly alarming arrangement, like an alarm thermometer, and unnecessary with a good powder stored under proper conditions, but which would cause commanders of warships to nervously watch their stores after the faintest indication, without giving them any remedy in midocean. The whole idea is not new, having been patented by Nicholson and Price in 1871.[b]

What we must aim at is an explosive which is durable and stable under all ordinary conditions of use, and even under some extraor-

[a] Chambre des Députés, "Rapport sur les causes de la catastrophe de l'Jena," Paris, 1907.

[b] British patent No. 2430, of September 15, 1871.

dinary ones, just as in the case of the old black powder. In the author's opinion, and his view is shared by very eminent colleagues, there can be no doubt that nitrocotton (and for the matter of that any other nitrocellulose) is not a suitable ingredient for a service powder. Having built or reconstructed a number of works and seen quite half of all those in Europe, he ventures to speak with some authority. Let us again recapitulate its defects. Made from a material which is most complex and liable to form unstable compounds, we elect to use it in a form which can neither be clean, nor of uniform growth, nor even of constant composition. The conditions of manufacture are such that in the absence of very special precautions the nitrocotton retains unstable compounds and is liable to decompose. Under the influence of heat, of certain additions or ingredients, of unsuitable treatment or friction, the nitrocotton may decompose and react in a progressive manner upon the other ingredients. It requires a solvent in order to be brought into a physical state which will permit the rate of burning of the powder to be regulated. Such solvent, if volatile, requires prolonged heating to drive it off as completely as possible. This heating helps to shorten the life of the powder, and any solvent remaining behind affects its ballistic properties. Nitrocellulose is not a uniform compound by any means, and it is almost impossible to make sure that every batch shall have the same composition and effect. The latter by no means depends on the percentage of nitrogen being the same, though this condition may be fulfilled by suitable blending. For instance, a mixture of soluble and insoluble nitrocellulose would not have the same effect as a nitrocellulose prepared direct, although each may contain the same percentage of nitrogen.

The question will naturally be asked, What will be the powder of the future? If we may venture a prophecy, the future belongs to a stable nitrocompound of the aromatic series, perhaps in conjunction with nitroglycerin. Such nitrocompounds have already been proposed, and sooner or later one will be found that meets all requirements. Although every service will be reluctant to make a change, yet having learned to appreciate the value of scientific research, some government will be sure to make a bold plunge, when all others will soon follow suit.

RECENT RESEARCHES IN THE STRUCTURE OF THE UNIVERSE.[a]

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INTRODUCTION.

I consider it an uncommon privilege to lecture on the structure of the universe in the country of the Herschels.

Even now their celebrated gauges are unrivaled, and they still form one of the important elements on which any theory of the stellar system must be based.

It is well known that the plan of these gauges consisted in directing the telescope successively to different points all over the sky, and simply counting the number of stars visible in the field.

REGULARITY IN THE ASPECT OF THE SKY.

There is one fact clearly brought out by these gauges to which I must call your attention. It is that in the outward appearance of our nightly sky, as seen with the telescope, there is a great regularity. In the Milky Way, that belt which we see with the naked eye encircling the whole of the firmament nearly along a great circle, the number of stars, as seen in Herschel's 20-foot reflector, is enormous. On both sides this apparent crowding of the stars diminishes very gradually and regularly, till near the poles of the Milky Way we come to the poorest parts of the sky.

VARIATION WITH GALACTIC LATITUDE.

Let us look at this phenomenon somewhat more closely. If we direct our telescope first toward the part of the Milky Way near Sirius, and if from there we gradually work up toward the North Pole of the Milky Way in the constellation called the "Hair of

[a] Lecture before the Royal Institution of Great Britain, London, Friday, May 22, 1908. Reprinted by permission.

Berenice," we shall clearly perceive this gradual and regular change in the number of stars. Now, if we repeat the same process, beginning from some other point of the Milky Way, say in Cassiopeia, or the Southern Cross, we shall find that, not only is there a similar gradual change, but we shall approximately go through the same changes.

LITTLE VARIATION WITH GALACTIC LONGITUDE.

At the same distance from the Milky Way we shall find approximately the same number of stars in the field of the telescope.

Put in other words: The richness of stars varies regularly with the galactic latitude; it varies relatively little with the galactic longitude.

Imitating most of the investigators of the stellar system, we will therefore disregard the longitude and keep in view only the changes with the galactic latitude. In reality this comes to being satisfied with a first approximation. For, in reality, there are differences in the different longitudes, especially in the Milky Way itself. But even here the differences are not so great as seems commonly to be supposed. There is every reason to believe, therefore, that our approximation will be already a tolerably close one.

REAL STRUCTURE.

Meanwhile what the Herschel gauges teach us is only relative to the outward appearance of the sky. What is the real structure of the stellar world? If we see so many stars in the field, with the telescope directed to the Milky Way, is it because they are really more closely crowded there, as Struve thinks, or is the view of the older Herschel correct, who imagined that the greater richness is simply a consequence of the fact that we are looking in deeper layers of stars; that our universe is more extensive in the Milky Way than it is in other directions?

Imagine that we could actually travel through space. For instance, imagine that first we travel in the direction of the constellation Cassiopeia. If we travel with the velocity of light, not so very many years would pass before we get near to some star. Proceeding on our journey for many, many more years, always straight on, we will pass more stars by and by. How will these stars look thus viewed from a moderate distance—say, from a distance as that of the sun?

Will they all be found to be of equal luminosity, as Struve practically assumed? And in this case are they as luminous as our sun, or more so, or less so? Or are they unequal?

If so, how many of them are brighter than our sun, how many fainter? Or, to be more particular, how many per cent of the stars are 10, 100, 1,000, etc., times more luminous than our sun? How many are equal to the sun, or 10, 100 times fainter? Or in two words: What is the nature of the mixture? Or, lastly, what is the mixture law of the system of the stars?

And furthermore, in traveling on shall we find the stars in reality equally thickly or rather thinly crowded everywhere? Or shall we find that after a certain time, which may be many centuries, they begin to thin out as a first warning of an approaching limit of the system? Is there really such a limit, which, once passed, leads us into abysses of void space?

Herschel thought there was such a limit, and even imagined that his big telescope penetrated to that limit; that is, he assumed that his telescope made even the remotest stars visible. On this supposition is based his celebrated disk theory of the system.

Again, we may condense these questions in this single query: How does the crowding of the stars, or the star density, that is the number of stars in any determined volume (let us say in a cubic light century) vary with the distance from our solar system?

But there is more. We supposed that our journey went straight on in the direction of Cassiopeia, which is in the Milky Way. What if our journey is directed to the Pleiades, which are at some distance from that belt, or to the Northern Crown, which is still farther, or to the Hair of Berenice, which is farthest of all from the Milky Way? For different regions equally distant from the galaxy we have seen that outward appearances are the same. We may admit, with much probability, that in space, too, we would find little difference. Summing up, the problem of the structure of the stellar system in a first approximation comes to this:

STATEMENT OF PROBLEM—TO DETERMINE, SEPARATELY FOR REGIONS OF DIFFERENT GALACTIC LATITUDE, IN WHICH WAY THE STAR DENSITY AND THE MIXTURE VARY WITH THE DISTANCE FROM THE SOLAR SYSTEM.

I think that there is well founded hope that, even perhaps within a few years, sufficient materials will be forthcoming which will allow us to attack the problem to this degree of generality, with a fair chance of success. At the present moment, however, our data are yet too scanty for the purpose. Still, they will be sufficient for the derivation of what must be in some sort average conditions in the system. The method of treatment will not be essentially different from that which will be applied later to the more general problem, but we have provisionally to be content with introducing the two following simplifications:

RESTRICTIONS.

1. We will assume that the mixture is the same throughout the whole of the system;

2. We will not treat the different galactic latitudes separately.

The consequence will be that the resulting variations of density to which our discussion leads, will not represent the actual variations which we would find if we traveled in space in any determined fixed direction, but a variation which will represent some average of what we would find on all our travels if we successively directed them to different regions of the sky.

SIMPLIFIED PROBLEM.

Our present problem will thus be confined to finding out:

(*a*) The mixture law.

(*b*) The mean star density at different distances from the solar system.

If time allows I will, at the end of this lecture, say a few words on the restrictions introduced and the way to get rid of them.

As it is not given to us to make such travels through space as here imagined, we have to rely on more human methods for the solution of our problem.

DETERMINATION OF DISTANCE.

It is at once evident that there would be no difficulty at all if it were as easy to determine the distance of the stars as it is to determine the direction in which they stand. For in that case the stars would be localized in space, and it would be possible to construct a true model from which the peculiarities of the system might be studied.

It is a fact, however, that, with the exception of a hundred stars at most, we know nothing of the distances of the individual stars.

What is the cause of this state of things? It is owing to the fact that we have two eyes that we are enabled not only to perceive the direction in which external objects are situated but to get an idea of their distance, to localize them in space. But this power is rather limited. For distances exceeding some hundreds of yards it utterly fails. The reason is that the distance between the eyes as compared with the distance to be evaluated becomes too small. Instruments have been devised by which the distance between the eyes is, as it were, artificially increased. With a good instrument of this sort distances of several miles may be evaluated. For still greater distances we may imagine each eye replaced by a photographic plate. This would even already be quite sufficient for one of the heavenly bodies, viz, for the moon.

At one and the same moment let a photograph of the moon and the surrounding stars be taken both at the Cape Observatory and at

the Royal Observatory at Greenwich. Placing the two photographs side by side in the stereoscope, we shall clearly see the moon "hanging in space," and may evaluate its distance.

But already for the sun and the nearest planets, our next neighbors in the universe after the moon, the difficulty recommences.

The reason is that any available distance on the earth, taken as eye distance, is rather small for the purpose. However, owing to incredible perseverance and skill of several observers and by substituting the most refined measurement for stereoscopic examination, astronomers have succeeded in overcoming the difficulty for the sun. I think we may say that at present we know its distance to within a thousandth part of its amount. Knowing the sun's distance we get that of all the planets by a well-known relation existing between the planetary distances.

But now for the fixed stars, which must be hundreds of thousands of times farther removed than the sun. There evidently can be no question of any sufficient eye distance on our earth. Meanwhile our success with the sun has provided us with a new eye distance 24,000 times greater than any possible eye distance on the earth. For now that we know the distance at which the earth travels in its orbit round the sun, we can take the diameter of its orbit as our eye distance. Photographs taken at epochs six months apart will represent the stellar world as seen from points the distance between which is already best expressed in the time it would take light to traverse it. The time would be about sixteen minutes.

However, even this distance, immense as it is, is on the whole inadequate for obtaining a stereoscopic view of the stars. It is only in quite exceptional cases that photographs on a large scale—that is, obtained by the aid of big telescopes—show any stereoscopic effect for fixed stars. By accurate measurement of the photographs we may perhaps get somewhat beyond what we can attain by simple stereoscopic inspection, but, as we said a moment ago, astronomers have not succeeded in this way in determining the distance of more than a hundred stars in all.

How far we are still from getting good stereoscopic views appears clearly from the stereoscopic maps which your countryman, Mr. Heath, constructed, making use of the data obtained in the way presently to be considered. In order to get really good pictures, he found it necessary to increase the eye distance furnished by the earth's orbit 19,000 times.

MOTION OF SOLAR SYSTEM THROUGH SPACE.

Are there, then, no means of still increasing this eye distance?

There is one way, but it is a rather imperfect one. Sir William Herschel has been the first to show, though certainly his data were

still hardly sufficient for the purpose, that the whole of the solar system is moving through space in the direction toward the constellation of Hercules. Later observations and computations have confirmed Herschel's conclusions, and we have even been able of late to fix with some precision the velocity of this motion, which amounts to 20 kilometers per second. This velocity is a fifteen-thousandth part of the velocity of light. In the one hundred and fifty years elapsed since Bradley determined for the first time the position of numerous stars with modern precision, the solar system must thus have covered a distance of exactly a hundredth part of a light year—i. e., we are thus enabled to make pictures of the sky as seen from points of view at a mutual distance of a hundredth of a light year. Our eye distance of sixteen light minutes is thus increased more than three hundred fold. True, this distance falls still considerably short of that adopted by Heath, but it appears that, for a considerable part of the stars, it is, though not nearly so great as might be desired, still in a certain way sufficient.

IMPOSSIBILITY OF DETERMINING DISTANCE OF INDIVIDUAL STARS.

There is, however, a difficulty in the way, which prevents our pictures from giving a stereoscopic view of the stars at all, and thus prevents the determination of the distance of any star in this manner. The difficulty is that the changed directions in which, after the lapse of one hundred and fifty years, we see the stars, is not exclusively the consequence of the sun's motion through space, but is due also to a real motion of the stars themselves. The two causes of displacement which, in the case that we take the diameter of the earth's orbit as eye-distance, are separable by means of a simple device, become inseparable in the present case.

In order to see whether this difficulty be or be not absolutely insuperable, I will take a parallel case on the earth.

DISTANCE OF INSECT CLOUD.

At a certain distance we observe a cloud of insects hovering over a small pond. In order to evaluate the distance separating the insects from our eye, suppose that we make a photograph; then, after a few seconds, a second one from a slightly different standpoint. It must be evident that even if we have used an instrument which clearly shows the individual insects, the two pictures put in the stereoscope will not furnish a stereoscopic view of them individually; on the contrary, the picture as seen in the stereoscope will be perfectly chaotic. The reason, of course, is that in the interval between the taking of the two photographs the insects have moved. Does it follow that an evaluation of the distance can be obtained?

The answer must be, of any individual insect, no; but of the cloud as a whole we can, provided that the cloud as a whole has not moved; or expressed more mathematically: Provided that the center of gravity of the cloud has not moved, we can derive the average distance[a] of all the insects. We shall be sure of the immobility of the center of gravity if we know that the direction of the motions of the insects is quite at random; but this is by no means required. The motion may be preferentially in a horizontal plane or along a determined line, say along the longer axis of the pond, provided only that the motions in any two opposite directions are equally frequent.

Not only that, even if the cloud, as a whole, is not immovable, we are not necessarily helpless. For, if the insect cloud and the photographer were both on a sailing vessel, circumstances would be the same as on the mainland, though now the cloud is in motion. Only, instead of the absolute displacement of the photographic apparatus, we must know the displacement relative to the ship, or rather relative to the insect cloud. This, then, finally is the real thing wanted. We may obtain the distance of the insect cloud, or what comes to the same, the average distance of its members, as soon as we are able to find out the displacement of our point of view with regard to the center of gravity of the cloud.

Our case is much the same in the world of the stars.

We shall be able to determine the average distance of the members of any arbitrary group of stars, provided that we can find the motion of the solar system, both in amount and in direction, relative to the center of gravity of the group.

Now, astronomical observations such as those which led the elder Herschel to his discovery of the solar motion through space enable us to determine the direction of the sun's motion relative to such groups as the stars of the third, fourth, etc., magnitude. Spectroscopy enables us to determine the amount of that motion.

We must be able, therefore, to find out the average distance of the stars in these groups. For other groups, such as the stars having an apparent centennial motion of 10″, 20″, etc., there is a difficulty. Still, however, we have succeeded in overcoming this difficulty by a somewhat indirect process, and pressing into service the stars of which the individual distances are known. This, then, is the upshot of astronomical work on the distances.

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[a] The expression "average distance" ought, strictly speaking, to be replaced by the distance corresponding to the average parallax. For sake of clearness I have ventured here and in what follows to substitute one expression for the other.

WHAT WE KNOW ABOUT STAR DISTANCE.

By direct measurement we know the distance of some hundred individual stars.

For the rest we know the average distance of any fairly numerous group of stars of determinate apparent magnitude and apparent motion.[a]

The question is: Can this imperfect knowledge of the distances be considered as in any wise sufficient for obtaining an insight into the real arrangement of the stars in space?

I think it can, and I will now try to show in what manner.

LOCALIZATION OF THE STARS IN SPACE BY A SORTING PROCESS.

The method may be best explained as a sorting process. The process was not actually followed; it would have been too laborious and would have met with some difficulty.[b] But the difference is immaterial, and the present description has, I think, the advantage in point of clearness.

Let each of the stars of the second, third, etc., to the eighth magnitudes be represented by a little card on which are inscribed the apparent magnitude and the apparent proper motion of the star.

Then imagine three sets of boxes.

CLASSIFICATION ACCORDING TO MAGNITUDE.

First set. Apparent magnitude boxes represented in figure 1.

In the box for the second apparent magnitude, as many cards are put as there are stars of the second magnitude in the sky. The total numbers of stars for each magnitude are inscribed on the lid. We thus see that there are in the whole of the sky 46 stars of the second magnitude, 134 of the third, and so on.

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[a] At the present moment some objection might certainly still be made against the generality of this statement. In fact, the scarcity of spectroscopic data is the cause that, though the determination of the solar motion separately for such groups as the stars of determinate magnitude and proper motion is quite possible, it has not yet been carried through. As a consequence the results used in what follows still rest on the assumption that the centers of gravity of all the groups considered are at rest relative to each other. That this assumption must be probably true, follows from the near identity of the direction of the sun's motions, furnished by the several groups.

[b] For many of the stars used the proper motion is still not known. What is known, however, is the percentage of the stars of each magnitude having a determined proper motion. This knowledge enables us to put in every box the required number of cards showing a determined proper motion, and this is all that is wanted in what follows.

FIG. 1.—Apparent Magnitude Boxes.

ACCORDING TO MAGNITUDE AND PROPER MOTION.

Second sets. Magnitude-motion boxes (fig. 2).

The stars in each of the former series of boxes are redistributed over a series of boxes, each of them containing stars of a determined apparent motion. By way of an example, figure 2 shows this new classification for the stars of the fifth apparent magnitude. There is, of course, another such series for each one of the apparent magnitudes. Those for the fifth have been distributed over 28 new boxes. In the first have been collected the cards representing the stars with a proper motion of 0″ to 1″ per century. The average motion is 0.5, and this has been inscribed on the lid. The little arrow indicates that this number represents a motion. The number 5 surrounded by a star refers to the fact that we have exclusively to do with stars of the fifth apparent magnitude. The second box contains the stars with proper motion between 1″ and 2″ per century, etc. For the larger motions the limits have been taken somewhat wider. In the eleventh box the motions 10″ to 15″ are contained; in the thirteenth, those between 20″ and 30″; and so on. The number of star cards in each box has been inscribed on the lower right-hand corner of the lid. The figure thus shows, for instance, that there are in the sky 90 stars of the fifth magnitude, having a proper motion between 0″ and 1″ per century. We have thus arranged the stars according to both the rough criteria of distance at our disposal. For we know perfectly well that in a very general way the fainter the stars and the smaller their apparent motion the farther they must be away.

For each of the groups thus obtained we are now able, according to what has been said before, to derive the mean distance. This determination being made, we obtain the mean distances expressed in light years which have been inscribed on the lid with the letter MD prefixed.

Already we may see now how incorrect it is to imagine all the stars of the fifth magnitude to be placed at one and the same distance as Struve placed them.

According to the numbers in our figure, the distance varies from 1670 light years for the stars of the first box, to 11 light years for those of the last. It is true that just the data for these extreme boxes are the most uncertain; still, it is evident that even in these mean distances there must be an enormous range.

But to proceed, the 86 stars in our sixth box (fig. 2) are at an average distance of 248 light years. Are we compelled to stop here and to assume that the real distance of all the individual 86 stars is

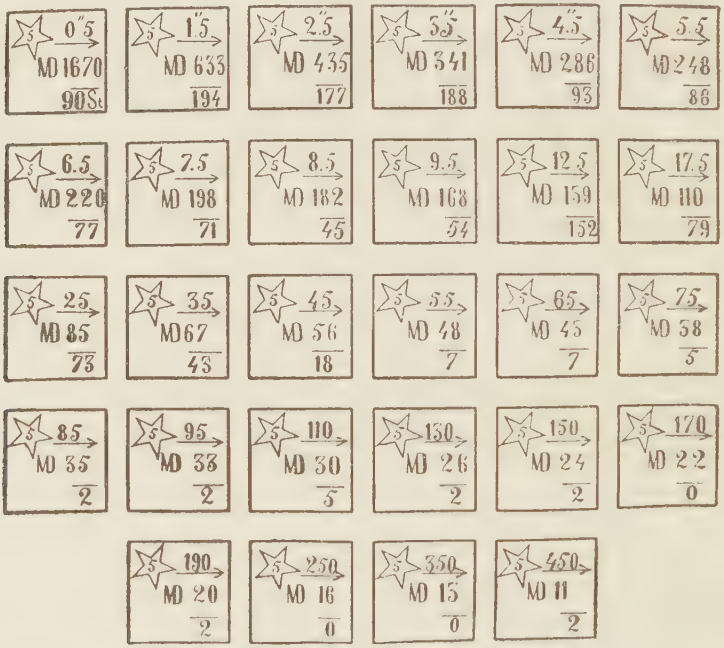

FIG. 2.—Magnitude-motion Boxes.

248 light years? If it were so we would surely still have gained a considerable advantage over Struve. For, owing to want of other data, he saw himself compelled to treat all the stars of the fifth magnitude, that is, the whole of the 28 groups in our boxes, as if they were all at the mean distance of the whole.

But yet there would remain in our solution a defect of the same kind, and it would be impossible to say in how far the results definitively to be obtained would be influenced.

Happily there is an escape. For our last classification, the classification in the distance boxes, it is of no particular advantage that every individual star gets in its proper distance box. It will be sufficient to know how many stars will finally be found in each distance

box. If this result is obtained, we shall presently see how easy it becomes to study the problem put at the beginning of this lecture. Our aim will be evidently reached if we can find out how many per cent of the stars in any one box have such and such a distance. Now, in order to determine these percentages, it will be sufficient to investigate a sample of our stars.

STARS OF MEASURED DISTANCE TAKEN AS A SAMPLE.

Happily there is the possibility of taking a sample that will help us out of the difficulty, for, as we know, there are in the sky a hundred stars of which astronomers have succeeded in determining the individual distance with some accuracy. We take these as our sample. They are distributed over a great many of our boxes.

We take them all out, having a care to note for all of them the mean distance of the stars in the box to which they belong. For all the hundred stars we now compare their mean distances to their true distances, and thus find out how many per cent of them have true distances between two and three. four and five tenths, and so on, of the mean distance.

Third set: Distance boxes.

These percentages are all we want for our last distribution, the distribution over the distances. It is true that our sample is a somewhat undesirably small fraction of the whole; it shows, besides, some other weak points; but it appears, happily, à posteriori, that even rather considerable uncertainties in these percentages have but an unimportant influence on the results. We are thus at last enabled to distribute our star-cards according to the true distances. I made the distribution over the spherical shells shown in figure 3.

The dimensions of these shells have been so chosen that if a star is removed from one shell to the next farther one, the observer at the center will see the star grow fainter by just one magnitude; that is, it will grow very nearly two and one-half times fainter.

The figure is not well fitted for bringing out the details of our results. The shells become too narrow toward the center and the more central ones do not allow of the insertion of sufficiently clear figures. For this reason I constructed figure 4. The numbers valid for the several spherical shells have here been entered in equally broad horizontal rows. The drawing does not, therefore, show the real dimensions, but these as expressed in light years, which may be read off on the right-hand side of the drawing. We thus see that the central sphere extends to a distance of 21 light years; that the second spherical shell extends from 21 to 33 years, and so on. In these rows a last set of boxes is placed. There is a box for each apparent mag-

nitude in each of the rows. The stars of the boxes of figure 2 are thus, of course, all contained in the vertical row of boxes, corresponding to apparent magnitude 5 in figure 4.

DISTRIBUTION ACCORDING TO DISTANCE ILLUSTRATED BY EXAMPLE.

In order to illustrate by an example how the stars of the boxes in our figure 3 are distributed over our different shells, that is over our distance boxes of figure 2, take the seventh box. It contains 77 stars at a mean distance of 220 light years. Our countings on the sample showed that about one-fifth of the stars have true distances which are

FIG. 3.—Distance Boxes.

between 37 and 59 per cent of their mean distance (derived from their apparent magnitude and proper motion). Therefore about one-fifth of our 77 stars must have true distances between 37 and 59 per cent of 220 light years; that is, between 82 and 130 light years; or, finally, 15 stars of our box must find their place in the fifth shell of figure 4; that is, in the box corresponding to the fifth apparent magnitude in that shell. In precisely the same way I find that 21 of them must be placed in the sixth shell, 18 in the seventh, 10 in the eighth, and so on.

If, after that, we repeat the process for all the remaining boxes of figure 2, we get, for the fifth apparent magnitude, the numbers inscribed on the lower side of the boxes corresponding to that magnitude in figure 4.

Further than for the eleventh shell no numbers have been entered. They become too uncertain. As, however, we know the total number of stars of each apparent magnitude, we know the aggregate number which remains to be distributed over the whole of the farther shells.

What has here been explained for the stars of the fifth magnitude, has been also done for the other magnitudes between the second and the eighth. The whole of the results are shown in our figure 4.

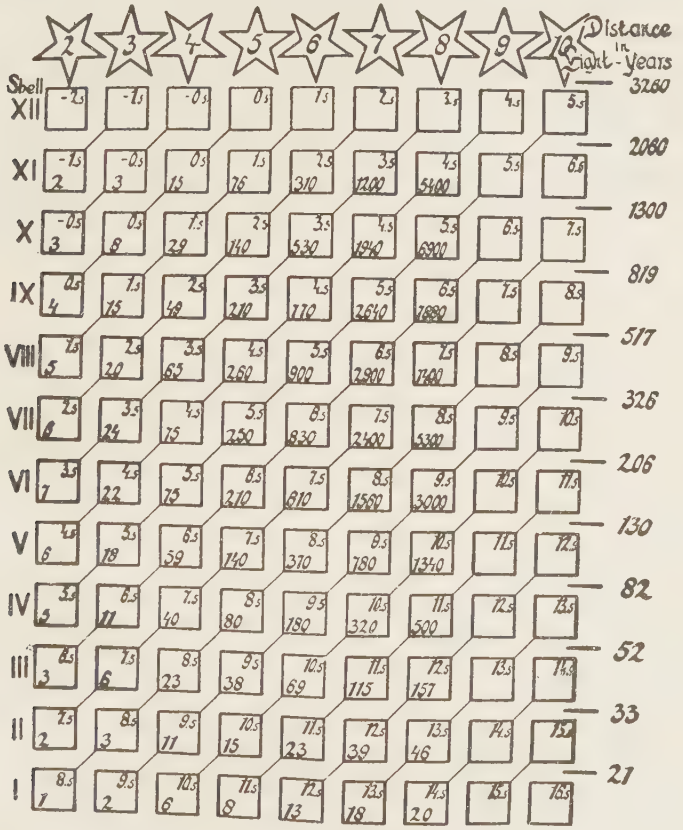

FIG. 4.—Distance Boxes, reconstructed diagram.

STARS OF EQUAL LUMINOSITY BROUGHT TOGETHER.

The main result of the investigation is embodied in these numbers—and first, in every box stars have now been brought together of equal absolute magnitude—that is, of equal luminosity. For as the stars in each box are at the same distance, and as, at the same time, they are of equal apparent brightness, they must, of necessity, be of equal total light-power; that is, according to our definition, of equal luminosity, or absolute magnitude. For the absolute magnitude of a star, I have taken the magnitude the star would show if placed at a dis-

tance of 326 light years. The choice of just this number is simply a matter of convenience, and need not be explained here.

As a consequence, the stars at a distance of 326 years, which to us appear as stars of the fifth magnitude, will have also the absolute magnitude 5. Those of the same apparent magnitude, but at a distance of 517 light years—that is, just one shell farther—must have the absolute magnitude 4 in order to show us the same brightness, notwithstanding the greater distance. Now, our eighth shell lies just between these limits of distance. In the middle of this shell, therefore, the stars of apparent magnitude 5 must have absolute magnitude 4.5. In the box, therefore, belonging to the fifth apparent magnitude, eighth shell, all the stars are of absolute magnitude 4.5. In the ninth shell a star must already have the absolute magnitude 3.5 in order to shine as a fifth apparent magnitude at this greater distance, and so on. In this way the absolute magnitudes were found which in our figure have been inscribed on the lids of the boxes.

MIXTURE LAW.

We are now able to derive at once the mixture law—i. e., the proportions in which stars of different absolute magnitude are mixed in the universe. For in one and the same shell (eleventh) we find two stars of absolute magnitude —1.5, as against three of magnitude —0.5, fifteen of absolute magnitude 0.5, seventy-six of absolute magnitude 1.5, etc.

That is, our results for the eleventh shell furnish us with the proportion in which stars of absolute magnitude —1.5, —0.5, etc., to 4.5, are mixed in space. The tenth shell gives the proportions for all the absolute magnitudes between —0.5 and 5.5, and so for the rest. All the shells together give the proportions for the absolute magnitudes —1.5 to 14.5, that is for a range of not less than sixteen magnitudes. Not only that, but most of the proportions are determined independently by the data of quite a number of shells. So, for instance, the proportion of the stars of absolute magnitude 4.5 to those of absolute magnitude 5.5. Each of the shells from the fifth to the tenth furnishes a determination of this proportion. All of them are not equally reliable. If we take this into account, we find that the agreement of the several determinations is fairly satisfactory. By a careful combination of all the results, a table representing the law of the mixture of the stars of different absolute magnitude was finally obtained. Rather than show you the direct result, however, I will first replace the absolute magnitudes by luminosities expressed in the total light of our sun as a unit. This will have the advantage of presenting a more vivid image of the real meaning of our numbers.

By photometric measures it was found that the sun, placed at a distance of 326 light years, would shine as a star of magnitude 10.5.

In other words, the sun's absolute magnitude is 10.5. A star of absolute magnitude 9.5 will, therefore, have 2.5 times the light-power—that is, 2.5 times the luminosity of the sun. A star of absolute magnitude 8.5 will again have a luminosity which is 2.5 times greater, and so on.

Such results evidently enable us to transform our absolute magnitudes into luminosities. Thus translated, I found the results shown in the following table.

LUMINOSITY TABLE.

Within a sphere having a radius of 555 light years, there must exist:

Stars.	Number of times more luminous than the sun.		
1	10,000	to	100,000
46	1,000	to	10,000
1,300	100	to	1,000
22,000	10	to	100
140,000	1	to	10
430,000	0.1	to	1
650,000	.01	to	0.1

This table represents what, up to the present time, we know about the mixture law.

The fainter the stars, the more numerous.

The rate at which the numbers increase with the faintness is particularly noticeable for the very bright stars.

Passing to the fainter stars, this rate gradually diminishes, and it looks as if we must expect no further increase in number for stars whose luminosity falls below one-hundredth of that of the sun. Meanwhile this is simply a surmise. For stars of this order of faintness data begin to fail. Here, as in nearly every investigation about the structure of the stellar system, the want of data for stars below the ninth apparent magnitude makes itself very painfully felt.

But let us come back to our figure 4. I will first remark that, knowing the mixture law, we can predict the number of stars that we shall get in the empty boxes belonging to the ninth, tenth, etc., magnitude, as soon as continued astronomical observations will permit us to include these stars in our discussion. For the mixture law, as derived just now, shows that in our universe the stars of absolute magnitude 4.5 is 5,400 (fig. 4), there must be 3.5 times 5,400, that is, magnitude 4.5.

Now as in the eleventh shell the number of stars of the absolute magnitude 4.5 is 5,400 (fig. 4), there must be 3.5 times 5,400, that is, 18,900 stars of absolute magnitude 5.5 in this shell. These belong all in the box of the ninth apparent magnitude of this shell. In the

same way we obtain the number of stars to be expected in the boxes of the tenth, eleventh, etc., apparent magnitude for all our shells down to the eleventh. There is exception only for the boxes belonging to the lower shells, for which the absolute magnitude would exceed 14.5.

It is evident, however, that the number of stars in these exceptional boxes must be small, and for what follows they are of little importance.

STAR DENSITY.

In the second place, our boxes now also lead to the determination of the star densities. For the volumes of the consecutive shells are perfectly known; they are in the proportion of 1 : 3.98. For the sake of convenience, let us say that the volume of each shell is exactly four times that of the next preceding one. Now, to take an example of the determination of the densities, consider the ninth and tenth shells (fig. 4). In the ninth there are 49 stars of absolute magnitude 2.5. Therefore, if in the tenth the stars were as thickly crowded as in the ninth, there would occur in this shell four times 49, that is, 196 stars of this absolute magnitude 2.5.

In reality we find but 140 of these stars. The conclusion evidently must be that the star density in the tenth shell is about $\frac{140}{196}$, that is about two-thirds of that in the ninth shell. A similar conclusion is obtained by comparing the number of the stars of absolute magnitude 3.5 in the two shells. The values obtained from the magnitudes 0.5 and 1.5 may be neglected. Owing to the exceedingly small number of stars, they must necessarily lead to untrustworthy results. From all the rest I found that the density in the tenth shell must be about 64 per cent of that in the ninth shell. The proportion between the densities in the other shells was determined in exactly the same way.

A slight defect in our results was then discovered.

We should exceed the limits of the time allowed for this lecture by entering into a consideration of this defect. It must be sufficient to state that it was not difficult to remove it. After that it appeared that the density in the first six of our shells is nearly the same. The density in these shells, that is, in the neighborhood of our sun, is such that about 2,000 stars of a luminosity exceeding one-hundredth that of the sun must be contained in a cubic light century. After the sixth shell the density diminishes gradually at such a rate that in the eleventh shell the density has fallen to about 30 per cent of what it is in the vicinity of the solar system.

In what precedes we tried to give a solution of the problem put at the beginning of this lecture—a solution, however, which embraces only that part of the universe which is contained within a distance of about 2,000 light years from our solar system.

STAR DENSITY FOR DISTANCES EXCEEDING TWO THOUSAND LIGHT YEARS.

Is there no possibility of getting beyond this distance?

I think there is; but of course you will not be astonished to find that the certainty of our conclusion diminishes as we get deeper and deeper in the abysses of space.

One of the reasons why the method thus far applied breaks down beyond the eleventh shell is that our data about proper motion are not refined enough to determine this motion with sufficient accuracy as soon as it is below 1″ in a century. Even the somewhat greater motions are rather uncertain. The proper motions thus can not help us much beyond a certain distance. But we have still one valuable element for the solution of our problem. This element is the total number of stars separately for the apparent magnitudes. Thanks mainly to the photometrical researches at the Harvard Observatory, it has become possible to determine with considerable accuracy the total number of stars of the first, second, etc., to the eleventh magnitude; with a fair degree of accuracy even those for the magnitudes down to the fourteenth (inclusive).

The density in the shells beyond the eleventh, not only for the stars down to the eighth apparent magnitude, but, according to what has been said a moment ago, also for the apparent magnitudes of 9, 10, etc., to 14, has to be determined in such a way that the addition of all the numbers in any one vertical column of figure 4 produces just these totals for the corresponding apparent magnitudes.

It can be proved that after the eleventh shell the density must, on the whole, continue to diminish. If we assume that this diminution is gradual and proportional to the increase in distance, it becomes very easy to determine the rate of this diminution, and consequently the distance at which the density becomes zero, that is the distance at which we reach the limit of the stellar system. We can not enter into fuller particulars here. It must be sufficient to say that in this way we are led to conclude that the further diminution of density must be slow, so slow that in the assumption made above, the limit of the system is only reached at a distance of some 30,000 light years.

HYPOTHESES UNDERLYING THE RESULTS.

In conclusion, a few words on the question: In how far are the results now obtained to be considered as established?

The answer must be: They can be considered to be established only in so far, and no farther, than we can trust the truth of the hypotheses which still underlie our reasoning.

For future consideration there thus remains the question, In how far can we test the validity of these hypotheses?

These hypotheses are the following:

1. The mixture was assumed to be the same at greater and smaller distances from the solar system.

2. The same was done for different distances from the galaxy.

3. The universe was assumed to be transparent, that is, it was assumed that the absorption of light in space is zero.

Can we get rid of these hypothetical elements?

I think we can, at least to a very great extent.

As to the first. Our figure 4 already goes far in enabling us to judge whether it is true or not, for evidently both our sixth and our ninth shell give the nature of the mixture, at least of the stars of absolute magnitude 3.5 to 6.5. Therefore, as far as these stars are concerned, we are able to see whether or not the mixture is the same at the distance of 650 light years as it is at the distance of 170 light years. Likewise the figure enables us to make the comparison in other cases. As soon as we possess the necessary data for a longer range of apparent magnitudes, say down to the fourteenth or fifteenth, we shall be able to dispense to a very large extent with our first hypothesis.

As to the second, the possible variation of the mixture with the distance from the Milky Way, it is largely only the question of treating the stars in different galactic latitudes separately. As far as I can see there are no particular difficulties in the way of such a separate treatment, at least not since the nature of certain anomalies in the distribution of stellar motions has been elucidated.

ABSORPTION OF LIGHT IN SPACE.

Last, not least, is the universe really absolutely transparent? There are reasons which make this seem very doubtful. A couple of years ago I obtained some evidence in the matter which shows that the absorption of light in space, if it exists to an appreciable amount, must at least be so small that over a distance of a hundred light years not more than a few per cent of the light can be lost. To determine so small an amount to within a small fraction of its total value will be a difficult task indeed. Still we can even now see definite ways, which, given the necessary data for very faint stars and nebulæ, will probably enable us to overcome this last difficulty.

COOPERATION FOR OBTAINING THE NECESSARY DATA FOR VERY FAINT STARS.

This want of data for very faint stars, which in the present investigation makes itself felt at every step, has led a number of astronomers to concerted action.

The express purpose of their cooperation is to collect data of every kind for stars down to the faintest that can practically be reached.

As complete observation and treatment of these numberless stars is out of the question, the plan is confined to a set of samples distributed over the whole of the sky.

CONCLUSION.

If, at the end of this lecture, somebody summarizes what has been discussed by saying that the results about the structure of the universe are still very limited and not yet free from hypothetical elements, I feel little inclined to contradict him. But I would answer him by summing up in another way, viz:

Methods are not wanting which, given the necessary observational data obtainable in a moderate time, may lead us to a true, be it provisionally still not very detailed, insight into the real distribution of stars in space.

I think this time need not exceed some fifteen years. They to whom such a time may still seem somewhat long may be reminded of the fact that that time will be elapsed, that we shall have finished our work, before any but a very few of our nearest neighbors in space can be aware of the fact that we have begun.

SOLAR VORTICES AND MAGNETISM IN SUN SPOTS.

[With 5 plates.]

By C. G. Abbot.
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At the present time the growth of knowledge of the sun is mainly through the applications of the spectroscope, although in the past information of great value was obtained by purely telescopic observations. Thereby the rotation of the sun was first measured, and the remarkable retardation of the rotation with increasing distance from the solar equator was established. Furthermore, it was discovered that the prevalence of sun spots waxes and wanes in periods which average about eleven years, although individual sun-spot cycles range from eight to fourteen years in length. By utilizing with the greatest art the rare instants of good seeing, Langley made his celebrated and beautiful drawings of the detailed structure within and around a typical sun spot. Similarly, by the selection of specially favorable conditions, Janssen was able to obtain photographs which show, as well as may be, the granular appearance of the general surface of the sun. Owing to the fortunate circumstance that the moon sometimes covers the body of the sun, leaving the surroundings open to view undimmed by the glare of the skylight, the beautiful structure of the corona and prominences became known from eclipse observations. Comparative studies of successive eclipses prove these features to be variable in high degree. The changes seen in the sun spots, prominences, and corona made it clear that very great rearrangements of the material of the sun go on continually; but if it were not for the aid of the spectroscope, knowledge of the character of these changes would probably forever be very meager.

Looking toward the sun we see through a layer of solar material, which, if we neglect the corona, may be several thousand miles deep. In this layer are contained the vapors of many of the elements found on the earth, notably of sodium, calcium, magnesium, iron, titanium, vanadium, chromium, and others, besides several of the permanent gases, like hydrogen and helium. Owing probably to the differing densities of these elements, and in a rough way connecting itself with their atomic weights, their distribution in level is not a homogeneous

mixture, but the heavier elements sink toward lower levels in general. Such partial separations in level and the vigorous motions which take place in the sun are effectually hidden to the telescopic observer, partly because he can not tell one transparent gas from another and partly owing to the circumstance that the motions at different levels are mixed beyond recognition on account of the great depth of the field of view. The separate currents are as undistinguishable as the separate motions of the motes of a wide sunbeam when viewed from a distance.

All this is changed for the spectroscope. Iron vapor strongly absorbs the rays of certain special wave lengths, and vapors of the other elements—hydrogen, calcium, etc.—do the like for still other rays. Hence instead of the brilliance due to the extremely hot interior layers of the sun there is found in the Fraunhofer lines chiefly the less intense emission of the cooler vapors of the elements which lie in the outer surface layers. If the sun is viewed in the red spectral line C (now usually called Hα), there is seen chiefly the hydrogen and not the iron, sodium, or other elements. Hydrogen has several other strong lines in the solar spectrum. Among the most conspicuous are Hβ (also called F) in the blue, Hγ and Hδ in the violet.

It is well known that when light is produced by heating a bar of iron or other substance to incandescence the light is at first red, and becomes white and, finally, in the electric arc, even of a violet tinge with increasing temperature. In short, the violet end of the spectrum requires a higher temperature for its copious emission than does the red. This holds in a general way for gases in their emission of line spectra as well as for solids with their continuous spectrum. Accordingly the red Hα line will be stronger with respect to the violet Hδ line when emitted from hydrogen gas at a lower temperature than at a higher one. Hence we may expect that if a mass of hydrogen gas extends for a very considerable thickness in the outer layers of the sun the spectrum of the higher and therefore cooler parts will be relatively stronger at Hα than at Hδ. Therefore if the sun is viewed only by Hα light, the aspect will be more that of the highest levels than of the lower ones. If viewed on the other hand through Hδ, or still more if one of the lines of iron is chosen, it will be on the whole more of the aspect of a lower section which is presented.

Readers will recall that the Smithsonian Report for 1904 contained an abstract of the account, by Hale and Ellerman, of the Rumford spectroheliograph of the Yerkes Observatory. Referring for details of the instrument to that publication, it is enough to say here that the spectroheliograph, invented by Hale about 1890, is to all intents and purposes a screen which limits the observer to rays of a single shade of color, and this may be at any part of the spectrum. By the aid of the spectroheliograph the sun may be photo-

graphed in hydrogen, calcium, or iron light, and in the case of hydrogen, which has lines in several parts of the spectrum, the light may be either violet, blue, or red. Spectroheliographic pictures show many details not seen in telescopic views of the sun. Mr. Hale has named the elementary patches which go to make up this newly found detail "flocculi." Recently very striking and interesting photographs of solar structure have been made by the spectroheliograph at the Mount Wilson Solar Observatory under Mr. Hale's direction, and the following abstract of an account of some of them is taken from his paper entitled "Solar Vortices:"[a]

SOLAR VORTICES.

The problem of interpreting the complex solar phenomena recorded by the spectroheliograph has occupied my attention since the first work with this instrument in 1892. The measurement of the daily motions in longitude of the calcium flocculi has led to several new determinations of the solar rotation,[b] and their areas, measured by a photometric method, are being used as an index to the solar activity. Various investigations on their forms at different levels,[c] their distribution in latitude and longitude, etc., have also been carried out. But the failure of the calcium flocculi to indicate the existence of definite currents in the solar atmosphere has been a disappointment.

The hydrogen flocculi, though occupying the same general regions on the sun's disk, are distinguished from those of calcium by several striking peculiarities. In the first place, most of them are dark, while the corresponding calcium (H_2) flocculi are bright. Secondly, as I have recently shown,[d] they seem to obey a different law of rotation, in which the equatorial acceleration (better, the polar retardation), shared by the spots, faculæ, and calcium flocculi, does not appear. A third peculiarity, briefly mentioned in previous papers, is clearly visible on many hydrogen photographs. It is a decided definiteness of structure, indicated by radial or curving lines, or by some such distribution of the minor flocculi as iron filings present in a magnetic field (see, for example, Astrophysical Journal, Vol. XIX, Pls. X and XII). First recognized at the beginning of our work with the hydrogen lines in 1903, this suggestive structure has repeatedly shown itself on the Mount Wilson negatives. But its true meaning did not appear until the results described in this paper had been obtained.

With the Rumford spectroheliograph the hydrogen lines Hβ, Hγ, and Hδ were used. Certain differences between the photographs, which seemed to depend upon the wave length, pointed to the desirability of trying Hα, but plates sufficiently sensitive to red light were not to be had at that time, and therefore the experiment was postponed.

The extreme sensitiveness in the red of plates prepared according to a formula due to Wallace[e] now renders it a simple matter to photograph the sun with Hα.

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[a] Astrophysical Journal, Vol. XXVIII (September), 1908. [The plate numbers do not correspond with those in original paper.—EDITOR.]

[b] Hale and Fox, The Rotation of the Sun, as Determined from the Motions of the Calcium Flocculi. Carnegie Institution (in press); Fox, Science, April 19, 1907; Hale, Contributions from the Mount Wilson Solar Observatory, No. 25; Astrophysical Journal, Vol. XXVII, p. 219, 1908.

[c] Hale and Ellerman, Publications of the Yerkes Observatory, Vol. III, pt. I.

[d] Hale, Contributions from the Mount Wilson Solar Observatory, No. 25; Astrophysical Journal, Vol. XXVII, p. 219, 1908.

[e] Astrophysical Journal, Vol. XXVI, p. 299, 1907.

Some preliminary work with the spectroheliograph attachment of the 30-foot Littrow spectograph of the tower telescope, in which I had the assistance of Mr. Adams, indicated that bright flocculi are more numerous and extensive when photographed with Hα than when Hδ is used. I then tried Hα with the 5-foot spectroheliograph of the Snow telescope, and immediately obtained excellent results. The images were stronger and of much better contrast than those given by Hδ. Moreover, the curved and radial structure surrounding sun spots was so striking as to lead to the hope that important advances might be expected to follow from the systematic use of the Hα line. * * *

This is so definite in form and so unmistakable in character as to satisfy the hopes aroused by the earlier photographs. It seems evident, on mere inspection of these photographs, that sun spots are centers of attraction, drawing toward them the hydrogen of the solar atmosphere. Moreover, the clearly defined whirls point to the existence of cyclonic storms or vortices. * * *

In the present paper I wish to illustrate the phenomena photographed with the aid of Hα in the neighborhood of a spot which reached the east limb of the sun at $8^h\ 16^m$ a. m. on May 26, 1908. A photograph of this spot, made by myself with Hα on May 29, at $4^h\ 26^m$ p. m. Pacific standard time, is reproduced in figure 1, plate 1. The whirl structure, which is clearly shown by this photograph, is also very distinct, though of somewhat different form, on the photograph of May 28. It is interesting to inquire as to the probable level of the region in which this whirl occurred, and the height of the long dark flocculus south of the spot. For this purpose we may examine photographs of the chromosphere and prominences at the limb, taken on May 25, 26, and 27. In the first of these, made on May 25 at $9^h\ 18^m$ a. m. (No. 4142), a long narrow prominence, extending toward the north, rises from the limb at position angle 92°, a point about one degree north of the spot. It makes an angle of about 12° with the limb, and fades out at the upper end, its length being approximately 90″ (geocentric). There are other small filamentary prominences in the region extending about 7° north of the spot, and smaller elevations in the chromosphere to the south. At position angle 98° a bright prominence rises to a height of about 20″ and then slopes to the chromospheric level at position angle 107°. Near its southern end is an independent filamentary prominence about 55″ high. On May 26, at $6^h\ 38^m$ a. m. (No. 4144), the prominences were photographed at the east limb. The lowest point in the chromosphere on this photograph corresponds to the position (position angle 93°) where the spot crossed the limb about two hours later. It will be seen that these prominences, which extend from position angle 82° to 106°, cover much of the region in which the whirl structure of plate 1 appears. The prominence south of the spot is very bright and its highest point reaches an elevation of about 35″. On May 27, at $5^h\ 22^m$ p. m. (No. 4152), a prominence about 25″ high extends from position angle 105° to 109°. This is doubtless the eastern extremity of the strong flocculus in plate 1, which may be there seen curving toward the spot.

We may now pass in rapid survey the more important photographs of the disk. On May 28, at $6^h\ 58^m$ a. m. (No. 4157), the spot is near the east limb and the whirls are well shown. To the east of the spot is a long, narrow line of bright hydrogen. On May 29, at $6^h\ 24^m$ a. m. (No. 4171), the whirls are very distinct and differ in many respects from those shown on May 28. Eruptive regions of bright hydrogen are seen southeast and west of the spot. The eastern end of the long, dark flocculus is changing in form, and bridges are appearing over the spot. Negative No. 4175, taken one hour and nineteen minutes later, seems to show distinct changes in the whirls, though they are not measurable. On May 29, at $4^h\ 26^m$ p. m. (No. 4176), the whirls resemble those shown in negative No. 4175, but exhibit some marked changes. An eruption which

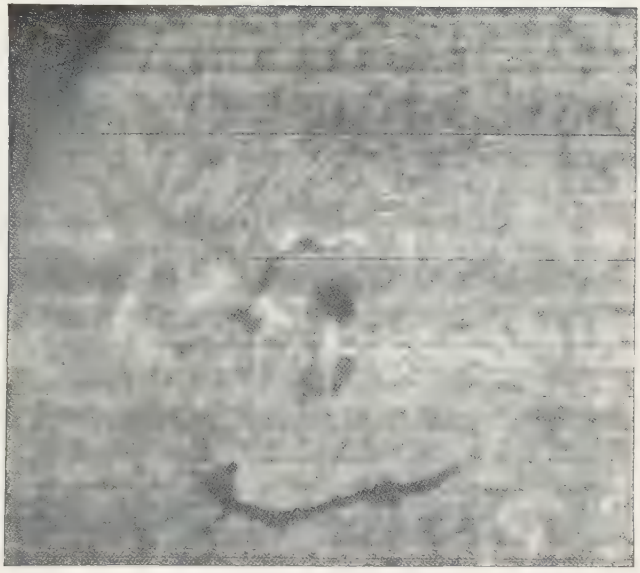

FIG. 1.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI.

1908, May 29, $4^h\ 26^m$ p. m. Scale: Sun's diameter=0.3 meter.

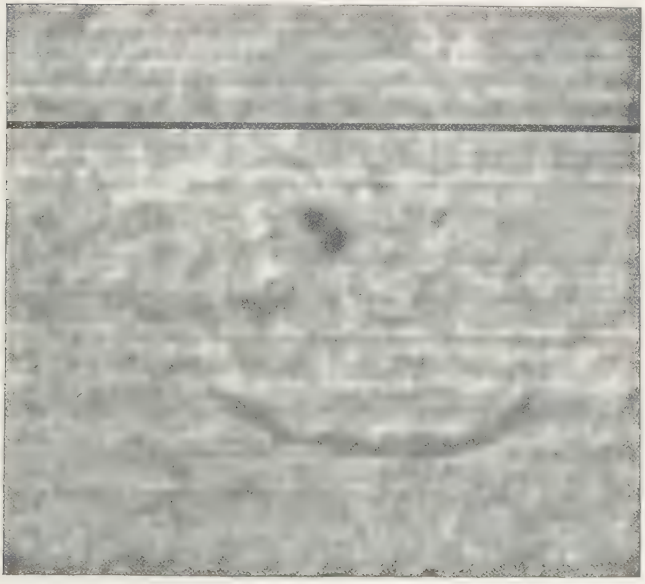

FIG. 2.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI.

1908, June 2, $6^h\ 10^m$ a. m. Scale: Sun's diameter=0.3 meter.

FIG. 1.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI.

1908, June 3, $5^h\ 22^m$ p. m. Scale: Sun's diameter=0.3 meter.

FIG. 2.—SUN-SPOT AND HYDROGEN ($H\alpha$) FLOCCULI.

1908, June 4, $6^h\ 12^m$ a. m. Scale: Sun's diameter=0.3 meter.

appears on the former plate southeast of the spot continues, but is changed in form and less brilliant than before. A strong eruption of peculiar form appears southwest of the spot, and bright hydrogen to the northeast. Strong, dark flocculi have also developed at many points around the spot. The eastern end of the long, dark flocculus is still changing, and a projection appears west of its center (see plate 1). A negative taken on the same day at $5^h\ 13^m$ p. m. No. 4178) shows further changes in both bright and dark structure, especially in the region southwest of the spot. A fork has developed in the western end of the long dark flocculus, and a small but very dark flocculus appears just west of the spot. Another photograph (No. 4179), the first exposure of which was made at $5^h\ 26^m$ p. m., shows a bright eruption west of the spot, where the small dark flocculus appears on No. 4178. The eruption underwent considerable change of form while the five exposures on this plate, separated by intervals of a few minutes, were being made. At $6^h\ 04^m$ p. m. negative No. 4181 shows that the eruption had subsided, and brings out other definite changes in structure near the spot. The small dark flocculus has disappeared. On May 31, at $8^h\ 09^m$ a. m. (No. 4188), the fork at the western extremity of the long dark flocculus has partially closed. No eruptions appear west of the spot, but there are bright ones to the southeast. Other important changes are evident, and the two bridges across the spot are conspicuous. On June 1, at $6^h\ 30^m$ a. m. (No. 4189), the fork at the western end of the long dark flocculus appears more nearly as it did in negative No. 4181, and the two bridges over the spot are very marked. A negative taken fifteen minutes later (No. 4190) shows distinct changes, especially in the region south and southeast of the spot. At $5^h\ 08^m$ p. m. of the same day negative 4193 shows a more distinct whirl near the spot, and the long dark flocculus appears to be growing shorter at its eastern end. On June 2, at $6^h\ 10^m$ a. m. (No. 4196), the whirling structure is very marked and more nearly symmetrical about the spot, which is divided into two parts (fig. 2, pl. 1). At $7^h\ 27^m$ a. m. (No. 4198) the whirl is also very marked and somewhat changed in form.

Up to this time the changes, while in many cases rapid, were not especially violent. On June 3, in an interval of about ten minutes, a remarkable transformation occurred. The long dark flocculus, which had been gradually changing in form and position, was suddenly drawn into the spot. As figure 2, plate 1, illustrates, the whirls were very conspicuous on the preceding day. A series of photographs, nine of which were made on negative No. 4201, between $4^h\ 48^m\ 09^s$ p. m. and $5^h\ 13^m\ 54^s$ p. m., and one, showing the entire disk, on negative No. 4202, at $5^h\ 22^m$ p. m., records the changes which took place during this time. These photographs were taken by Dr. C. E. St. John, who joined the observatory staff in May, and is sharing with me the observation work with the five-foot spectroheliograph during Mr. Ellerman's absence on vacation. Three of these have been selected for reproduction. Figure 1, plate 2, is enlarged from a photograph made at $4^h\ 58^m\ 16^s$ p. m. (time of transit of spot across collimator slit of spectroheliograph). At $5^h\ 01^m\ 21^s$ the large dark flocculus is apparently unchanged in form. At $5^h\ 04^m\ 21^s$ an exposure, which is not quite so well defined, gives no certain evidence of change. The next exposure, made at $5^h\ 07^m\ 06^s$, clearly shows the development of a fork at the eastern end of the flocculus, with traces of a very faint curved extension toward the larger spot. * * * The next exposure, made at $5^h\ 10^m\ 52^s$, shows the fork and part of the extension, but the definition is poor and the position of the end of the extension uncertain. The last exposure on this plate, made at $5^h\ 13^m\ 54^s$, is reproduced in figure 2, plate 2. * * * The spot region on negative No. 4202, made at $5^h\ 22^m$ p. m. (time of transit of spot), is reproduced in figure 1, plate 3. Here the definition and contrast are also poor, but the extension reaching nearly to the

spots, is sufficiently well shown, as well as a dark flocculus which developed southeast of the smaller spot. * * *

If we call C the point of nearest approach of this flocculus to the spot, we have the following results of measurements: Between exposures 6 and 7 we find for the point C a change of 1.9° in latitude and 1.5° in longitude. This corresponds to a motion of 2.4° in 195 seconds, or 177 kilometers per second. Between exposures 7 and 9, in an interval of 408 seconds, there was a change of 3° in latitude and 0.4° in longitude, giving a velocity of 89 kilometers per second. Eight minutes later[a] the extension had divided and moved nearly to the spots, the resultant motion for each extremity being 2.8°, giving a velocity of 71 kilometers per second. * * *

The differences among the three velocities can not be trusted, though the evidence favors the view that the first velocity was actually higher than the others. The mean of the six measures (106 kilometers) will at least serve to give the order of the maximum velocity in the vortex.

The appearance of the spot and surrounding region thirteen hours after the rapid changes described above is shown in figure 2, plate 3. The straight radial lines in this photograph are in marked contrast to the curved structure previously shown. The eastern of the more plainly marked radial lines is found by measurement to be a short distance to the east of the extension from the large flocculus to the spots shown in figure 2, plate 3. The forked connection to the two spots has disappeared and a strong dark flocculus has developed at the southern extermity of the radial line, mainly on its eastern side. In the photograph of June 5, $7^h\ 05^m$ a. m. (No. 4220), the radial structure surrounding the spots is greatly altered and the flocculus, no longer recognizable, has developed a large extension toward the west. A notable feature of this photograph is the amount of bright eruptive hydrogen in the region surrounding the two spots. Some eruptive matter also appears in the photographs of the preceding day, but here it is greatly augmented. * * *

As already remarked, the distance from the spot of the western extermity of the large flocculus did not vary systematically. The eastern extremity, on the contrary, commenced on June 1 to approach the spot, and continued to do so until the sudden change occurred on June 3. Up to this time the velocity, instead of showing signs of acceleration, was apparently retarded, but the changing form of the flocculus leaves this point uncertain. On the photograph of May 29 (No. 4176) the whirl is most conspicuous north of the spot, where its extreme distance is about equal to that of the western end of the large flocculus. Apparently, however, the flocculus did not fall completely under the influence of the vortex until June 1, when its eastern extremity was 11.4°= 140,000 kilometers from the spot. The fact that the minimum distance of the western end always exceeded this quantity may account for its escape. * * *

It may be well to direct attention to certain points which have been noted:

In the series of photographs (on negatives Nos. 4201 and 4202) which show the large flocculus in the act of being drawn into the spots, the small flocculi near the spots remain almost unchanged in position, perhaps because of difference of level.

Except in the case of the large flocculus, attempts to detect evidences of motion toward the spots have not yet proved successful, even along apparent lines of flow.

Negative No. 4196, taken on June 2, shows a dark cometlike object (apparently defining a line of flow) intersecting a bright eruptive flocculus. The appearance suggests that the eruption does not rise to the level of the vortex. * * *

[a] The time of negative No. 4202 is recorded only to the nearest minute.

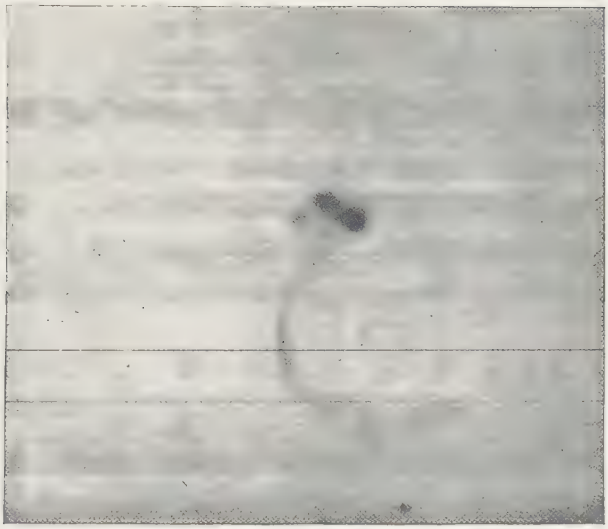

FIG. 1.—SUN-SPOT AND HYDROGEN (*Hα*) FLOCCULI.
1908, June 3, $4^h\ 58^m\ 16^s$ p. m. Scale: Sun's diameter=0.3 meter.

FIG. 2.—SUN-SPOT AND HYDROGEN (*Hα*) FLOCCULI.
1908, June 3, $5^h\ 13^m\ 54^s$ p. m. Scale: Sun's diameter=0.3 meter.

Without entering at present into further details, a single suggestion relating to the possible existence of magnetic fields on the sun may perhaps be offered. We know from the investigations of Rowland that the rapid revolution of electrically charged bodies will produce a magnetic field, in which the lines of force are at right angles to the plane of revolution. Corpuscles emitted by the photosphere may perhaps be drawn into the vortices,[a] or a preponderance of positive or negative ions may result from some other cause. When observed along the lines of force, many of the lines in the spot spectrum should be double, if they are produced in a strong magnetic field. Double lines, which look like reversals, have recently been photographed in spot spectra with the 30-foot spectrograph of the tower telescope,[b] confirming the visual observations of Young and Mitchell. It should be determined whether the components of these double lines are circularly polarized in opposite directions, or, if not, whether other less obvious indications of a magnetic field are present. I shall attempt the necessary observations as soon as a suitable spot appears on the sun.

A MAGNETIC FIELD IN SUN SPOTS.

Carrying out his projected observations on the polarization of sun spot spectrum lines, Mr. Hale has obtained a most striking proof of the existence of magnetic fields in sun spots. An abstract of his paper[c] on this subject follows:

The discovery of vortices surrounding sun spots, which resulted from the use of the hydrogen line Hα for solar photography with spectroheliograph[d] disclosed possibilities of research not previously foreseen. Photographs taken daily on Mount Wilson with this line suggest that all sun spots are vortices, and provide material for a discussion of spot theories which will soon be undertaken. Revealing, as they do, the existence of definite currents and whirls in the solar atmosphere, they afford the requisite means of testing the operation in the sun of certain physical laws previously applied only to terrestrial phenomena. The present paper describes an attempt to enter one of the new fields of research opened by this recent work with the spectroheliograph.

ELECTRIC CONVECTION.

In 1876 Rowland discovered that an electrically charged ebonite disk, when set into rapid rotation, produced a magnetic field, capable of deflecting a magnetic needle suspended just above the disk.[e] It thus appeared, in accordance with Maxwell's anticipation, that a rapidly moving charged body gives rise to just such effects as are caused by an electric current flowing through a wire. Rowland's whirling disk therefore corresponds to a short wire helix, within which a magnetic field is produced when a current is passed through it.

Recent studies of the discharge of electricity in gases prove that gases and vapors, when ionized by one of several means, contain electrically charged

[a] J. J. Thomson, Conduction of Electricity through Gases, p. 164.

[b] Hale, Contributions from the Mount Wilson Solar Observatory, No. 23; Astrophysical Journal, Vol. XXVII, p. 204, 1908.

[c] Astrophysical Journal, Vol. XXVIII (November), 1908.

[d] Hale, "Solar Vortices," Contributions from the Mount Wilson Solar Observatory, No. 26; Astrophysical Journal, Vol. XXVIII, p. 100, 1908.

[e] Rowland, "On the magnetic effect of electric convection," American Journal of Science (3), Vol. 15, p. 30, 1878.

particles. Moreover, at high temperatures carbon and many other elements which occur in the sun emit negatively charged corpuscles in great numbers; the complementary positively charged particles must also be present, more or less completely separated from the negative corpuscles.[a] Thus electro-magnetic disturbances on a vast scale may result from the rapid motions of charged particles produced by eruptions or other solar disturbances.

Soon after the discovery of the vortices associated with sun spots it occurred to me that if a preponderance of positive or negative ions or corpuscles could be supposed to exist in the rapidly revolving gases, a magnetic field, analogous to that observed by Rowland in the laboratory, should be the result. An equal number of positive and negative ions, when whirled in a vortex, would produce no resultant field,[b] since the effect of the positive charges would exactly offset that of the negative charges. But Thomson's statement regarding the possible copious emission of corpuscles by the photosphere, and the tendency of negative ions to separate themselves, by their greater velocity, from positive ions, led to the belief that the conditions necessary for the production of a magnetic field might be realized in the solar vortices.

Thanks to Zeeman's discovery of the effect of magnetism on radiation it appeared that the detection of such a magnetic field should offer no great difficulty, provided it were sufficiently intense. When a luminous vapor is placed between the poles of a powerful magnet the lines of its spectrum, if observed along the lines of force, appear in most cases as doublets, having components circularly polarized in opposite directions. The distance between the components of a given doublet is directly proportional to the strength of the field. As different lines in the spectrum of the same element are affected in different degree, it follows that in a field of moderate strength many of the lines may be simply widened, while others, which are exceptionally sensitive, may be separated into doublets.

THE SUN-SPOT SPECTRUM.

It has long been known that the spectrum of a sun spot differs from the ordinary solar spectrum in several particulars. If, for example, we examine the iron lines in a spot we find that some of them are more intense than in the solar spectrum, while others are weaker. Again, we perceive that many of the spot lines are widened and that the degree of widening varies for different lines. Finally, if the observations are made with an instrument of high dispersion it will be seen that some of the iron lines which are single in the solar spectrum are double in the spot spectrum. Such double lines were first seen by Young in 1892 with a large spectroscope attached to the 23-inch Princeton refractor. Walter M. Mitchell, who subsequently observed them with the same instrument, described the doublets as "reversals," which they closely resemble. Mitchell's papers contain a valuable series of observations of these "reversals" and other sun-spot phenomena.[c] * * *

Our investigations in this field on Mount Wilson have given the first photographic records of the "reversals" or doublets seen visually by Young and Mitchell, and reveal thousands of faint lines beyond the reach of visual observation. * * *

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[a] J. J. Thomson, Conduction of Electricity through Gases, p. 165.

[b] Unless separated by centrifugal force, as suggested by Professor Nichols.

[c] Walter M. Mitchell, "Reversals in the spectra of sun spots," Astrophysical Journal, Vol. XIX, p. 357, 1904; "Researches in the sun-spot spectrum, region F to a," ibid., Vol. XXII, p. 4, 1905; "Results of solar observations at Princeton, 1905–1906," ibid., Vol. XXIV, p. 78, 1906.

Investigations on the spectra of iron, manganese, chromium, titanium, vanadium, and other metals conspicuous in spots, made with the arc, spark, and flame, indicated that the change of the relative intensity of lines observed in passing from the solar spectrum to the spot spectrum is due to a reduction of the temperature of the spot vapors.[a] Subsequent work with a new electric furnace by Doctor King,[b] the details of which have not yet been published, seems to leave little doubt that this explanation is correct. It is supported by the presence in the spot of compounds which appear to be dissociated at the higher temperature outside the spot, and by the resemblance of spot spectra to the spectra of red stars.[c]

While our investigations have thus furnished a plausible explanation of some of the characteristic phenomena of sun-spot spectra, the widening of lines and the presence of doublets are among the remaining peculiarities that demand consideration. As we have seen, however, these very peculiarities are precisely what would be expected if a magnetic field were present. Prompted by the theoretical considerations outlined above, and encouraged by their apparent agreement with the facts of observation, I decided to test the components of the spot doublets for evidences of circular polarization and to seek for other indications of the Zeeman effect.

METHOD OF OBSERVATION.

The tower telescope forms an image of the sun, about 6.7 inches (17 centimeters) in diameter, on the slit of a vertical spectrograph of 30 feet focal length. This instrument, to which reference has already been made, stands in a well with concrete walls, the grating being about 26½ feet (8 meters) below the surface of the ground. The temperature at the bottom of the well is so constant that exposures of any desired length may be given, without danger of a shift of the lines resulting from expansion or contraction of the grating. A Fresnel rhomb and Nicol prism[d] are mounted above the slit, so that the light of the solar image passes through them. If the doublets in spots are produced by a magnetic field, the light of their components, circularly polarized in opposite directions, should be transformed by the rhomb into two plane polarized rays, differing 90° in phase. Thus, in a certain position of the Nicol, the

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[a] Hale, Adams, and Gale, "Preliminary paper on the cause of the characteristic phenomena of sun-spot spectra," Contributions from the Mount Wilson Solar Observatory, No. 11; Astrophysical Journal, Vol. XXIV, p. 185, 1906; Hale and Adams, "Second paper on the cause of the characteristic phenomena of sun-spot spectra," Contributions from the Mount Wilson Solar Observatory, No. 15; Astrophysical Journal, Vol. XXV, p. 75, 1907.

[b] King, "An electric furnace for spectroscopic investigations, with results for the spectra of titanium and vanadium," Contributions from the Mount Wilson Solar Observatory, No. 28; Astrophysical Journal, Vol. XXVIII, p. 300, 1908.

[c] Hale and Adams, "Sun-spot lines in the spectra of red stars," Contributions from the Mount Wilson Solar Observatory, No. 8; Astrophysical Journal, Vol. XXIII, p. 400, 1906; Adams, "Sun-spot lines in the spectrum of Arcturus," Contributions from the Mount Wilson Solar Observatory, No. 12; Astrophysical Journal, Vol. XXIV, p. 69, 1906.

[d] Obtained for this purpose in 1905, when the idea of searching for the Zeeman effect in sun spots had already occurred to me. A visual test of the spot lines for plane polarization, made with the 18-foot spectrograph in 1906, before we had photographed the doublets, gave negative results.

light from the red component should be transmitted and that of the violet component cut off. When rotated 90° in azimuth, the Nicol should transmit the violet component and cut off the red component. Complete extinction of either component is hardly to be expected, because the light from the spot does not, in general, come exactly along the lines of force, and the doublets may therefore exhibit some traces of elliptical polarization. Moreover, the beam of sunlight undergoes two reflections on the silvered surfaces of the coelostat and second mirrors of the tower telescope, where elliptical polarization must again be introduced.[a] By setting the rhomb at the proper angle, the latter effect, which is not very large, can be almost wholly eliminated, but the former may play some part, even when the spot is at the center of the sun.

The light of the spot, after transmission through the rhomb and Nicol, comes to a focus in the plane of the slit. While photographing the spot spectrum the slit is covered except at its central part, where a portion corresponding in length (from 1 to 2 millimeters) to the diameter of the umbra, receives the light. During the exposure, which may continue from a few minutes to over an hour, the image of the umbra is kept as nearly as possible central on the slit, any irregularities in the motion of the driving clock being corrected by the observer. As the exposure for the spot spectrum is from five to twenty times as long as for the solar spectrum, it is evident that care must be taken to prevent light from regions outside the spot from entering the slit.

For a comparison spectrum sunlight is used, generally from a point in the solar image a short distance away from the spot, where none of the characteristic spot phenomena appear. During the exposure, that part of the slit which previously received the light of the umbra is covered, and sunlight admitted on either side. The light of the comparison spectrum passes through the rhomb and Nicol, both of which occupy the same positions as in the case of the spot. Care is taken to see that the grating is fully illuminated, both for the spot and comparison spectra, in all positions of the Nicol.

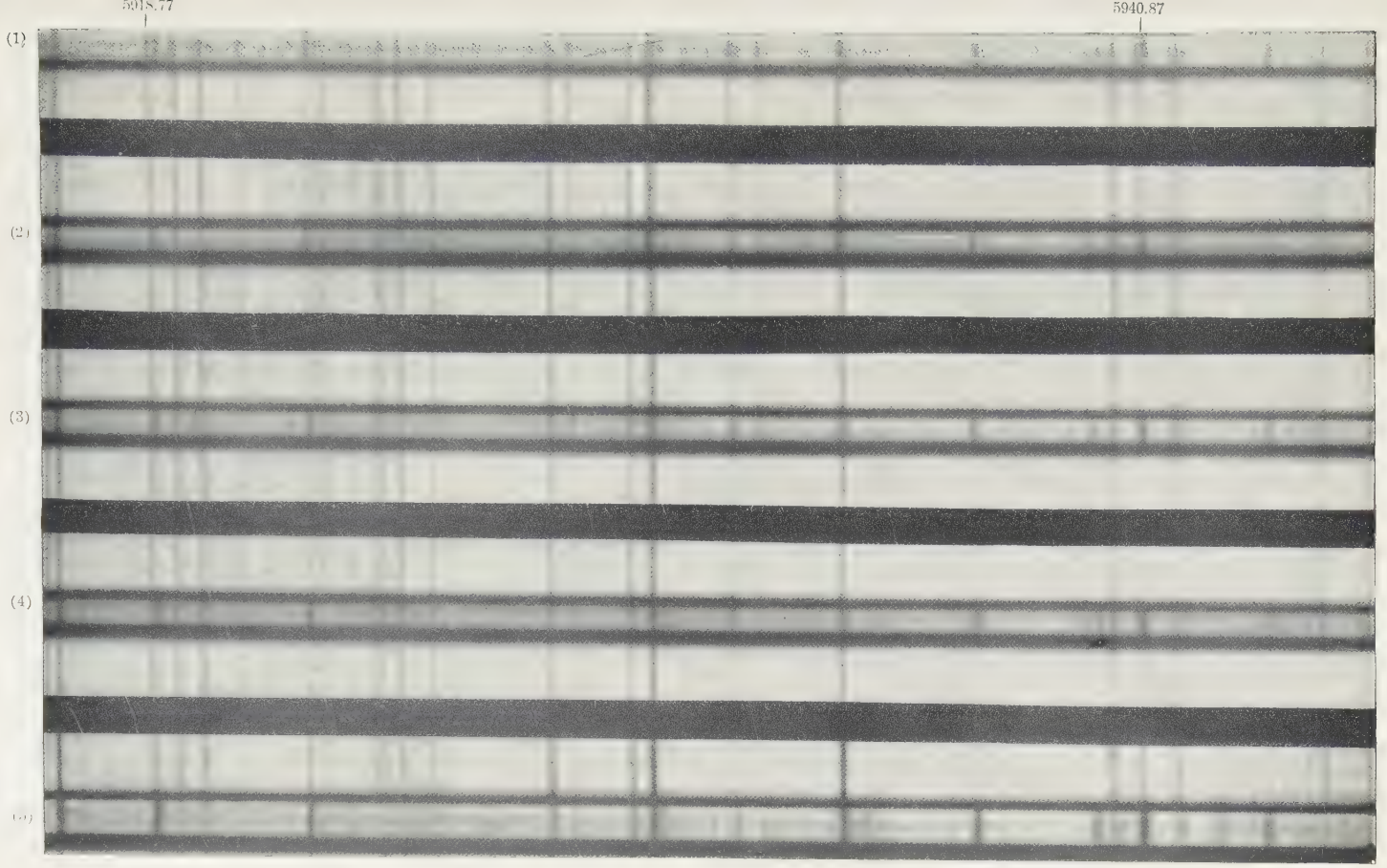
CIRCULAR POLARIZATION ALONG THE LINES OF FORCE.

My first observations were made on June 24, in the second order of the grating, but the results were not conclusive. On June 25 I obtained some good photographs in the third order, of the region λ 6000–6200, using Seed's process plates, sensitized for the red by Wallace's three-dye formula.[b] These clearly showed a reversal of the relative intensities of the components of spot doublets when the Nicol was turned through an angle of 90°. Moreover, many of the widened lines were shifted in position by rotation of the Nicol, indicating that light from the edges of these lines is circularly polarized in opposite directions. The displacements of the widened lines appeared to be precisely similar in character to those detected by Zeeman in his first observations of radiation in a magnetic field.

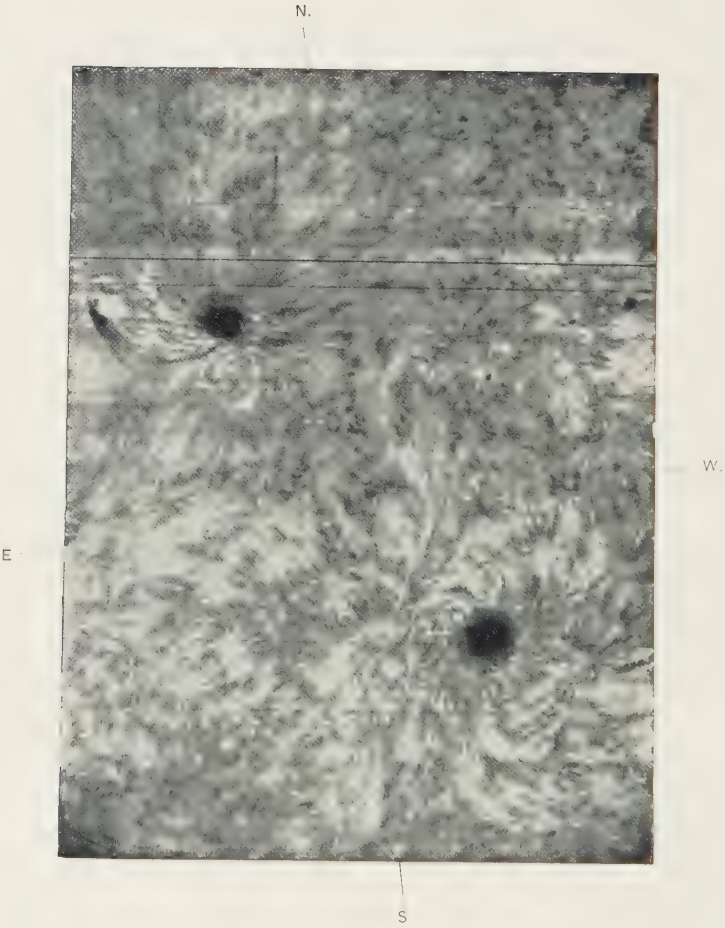
A series of photographs, made with the Nicol set at various angles, soon showed the two positions giving the maximum effect. At these positions the weaker components of the strongest doublets are not always completely cut off, but their intensities are greatly reduced. Sometimes hardly a trace of the weaker component remains, as may be seen in the case of the vanadium doublet at λ 5940.87 (pl. 4). In this plate No. 5 shows the doublet in the ordinary spot spectrum, photographed without the rhomb and Nicol. No. 4,

[a] A study of the elliptical polarization of these mirrors has been made by Doctor St. John.

[b] Astrophysical Journal, Vol. XXVI, p. 299, 1907.



(1) Southern spot, showing red components of doublets. Nicol, 29° W. (2) One umbra of northern spot, showing violet components of doublets. Nicol, 29° W. (3) Other umbra of northern spot, showing violet components of doublets. Nicol, 29° W. (4) Same umbra of northern spot, showing red components of doublets. Nicol, 61° E. (5) Spot spectrum without Rhomb or Nicol, showing both components of doublets. Scale: 1 Angström



SUN-SPOTS AND HYDROGEN FLOCCULI, SHOWING RIGHT AND LEFT HANDED VORTICES.

1908, September 9, $6^h\ 20^m$ a. m. Scale: Sun's diameter = 0.3 meter.

from a photograph (T 190) made with the Nicol set at 61° E., shows only the red component of the doublet. No. 3 illustrates the effect of turning the Nicol 90°; only the violet component remains. Other spot lines in these photographs change in a similar way.

Photographs like these seemed to leave no doubt that the components of the spot doublets are circularly polarized in opposite directions. Since the only known means of transforming a single line into such a doublet is a strong magnetic field, it appeared probable that a sun spot contains such a field, and that the widening and doubling of the lines in the spot spectrum result from this cause. But much remained to be done before the proof could be regarded as complete.

Since this preliminary work I have made over 200 photographs of spot spectra with polarizing apparatus before the slit. In addition to this collection of plates, numerous photographs of spot spectra, some taken with polarizing apparatus by Doctor St. John, and others made without Nicol or rhomb by Mr. Adams and myself, are available for study. These have been used for the investigation described in the following pages.

REVERSED POLARITIES OF RIGHT AND LEFT HANDED VORTICES.

If a Nicol is set so as to cut off the violet component of a doublet observed along the lines of force of a magnetic field, reversal of the current will cause the red component to disappear and the violet component to become visible. Reversal of the direction of the current in a magnet corresponds to reversal of the direction of revolution in a solar vortex. If it could be shown, by an independent method, that in two sun-spot vortices the charged particles are revolving in opposite directions, the red components of the doublets should appear in the spectrum of one spot, and the violet components in that of the other, the position of the rhomb and Nicol remaining unchanged.

Fortunately the spectroheliograph plates indicate the direction of revolution in the solar vortices. The vortices are constantly changing in appearance, and the stream lines are not always clearly defined. Plate 5 is reproduced from a photograph of the sun made by Mr. Ellerman with the 5-foot spectroheliograph on September 9 and 10. It shows two spots, one in the northern, the other in the southern hemisphere, with vortices indicating revolution in opposite directions, if we may judge from the curvature of the stream lines.[a] Portions of the spectra of these spots, photographed by myself on September 9, are reproduced in plate 4. No. 1 shows the spectrum of the southern spot, in which the direction of revolution was clockwise, taken with the Nicol set at 29° W. Only the red components of the doublets appear. The northern spot, in which the revolution was counter clockwise, was then photographed (2). Although the Nicol and rhomb remained in the same position as before, the red components of the doublets are now cut off, while the violet ones are visible. During this exposure the slit was kept on the western umbra of the northern spot, which was divided into two parts by a bridge (not shown in the reproductions). Another exposure, with Nicol and rhomb as before, was then made on the eastern umbra of the same spot (3), with results similar to those obtained for the western umbra. For the final exposure (4) the slit was kept on the eastern umbra of the northern spot, and the Nicol rotated 90°. As was to be expected, the red components were brought into view, and the violet components extinguished. This spectrum is therefore precisely similar to that of the southern spot, which was taken with the Nicol in the reverse position.

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[a] Right and left handed vortices have also been found in the same hemisphere.

This result has been confirmed by other photographs, which indicate that the direction of the displacement always depends upon the direction of revolution in the vortex.

PLANE POLARIZATION ACROSS THE LINES OF FORCE.

So far we have confined our attention to polarization phenomena observed along the lines of force. But it is well known that the doublets are, in general, transformed into triplets when observed in a magnetic field at right angles to the lines of force. The components of the triplets are plane polarized, the central line in a plane at right angles to the plane of polarization of the side components. It should be possible to detect similar phenomena in spot spectra, if they are produced in a magnetic field.

It naturally happens that these spectra are most commonly observed when the spots are not very far removed from the center of the sun, because foreshortening near the limb reduces the umbra to a narrow strip difficult to keep on the slit. This may partially explain why our photographs of spot spectra, taken without polarization apparatus, show the doublets without a trace of a central component. But it does not account for the failure of the central line to appear in the spectra of spots well removed from the center. It is true that a few triplets occur in all of our spot spectra, such as λ5781.97, λ6064.85, and λ6173.55. But these I have regarded as probable examples of an exceptional type of lines, observed in the laboratory as triplets along the lines of force.

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LABORATORY TESTS.

If the widened lines and doublets in spot spectra are produced by a magnetic field, an equal degree of widening and an equal separation of the components of doublets should be found in the laboratory when the same lines are observed in a field of equal strength. As the necessary apparatus was fortunately available, the work was at once undertaken in our Pasadena laboratory by Doctor King. A brilliant spark is produced by a high potential transformer between electrodes supported in the field of a large Du Bois magnet. The light, passing through the pierced pole pieces, falls on a lens, which forms an image of the spark on the slit of a vertical spectrograph, after reflection on a mirror mounted at an angle of 45° above the slit. This spectrograph, which is precisely similar to the 30-foot spectrograph used with the tower telescope, also stands in a constant temperature well, with the slit about 3 feet above the floor of the laboratory.[a] It may be used as an instrument of 30 feet focal length, or, as in the present case, a 5-inch (13 centimeters) objective of 13 feet (4 meters) focal length, with a 5-inch plane grating, having 14,438 lines to the inch (567 to the millimeter), can be swung into the axis of collimation 13 feet below the slit. With this shorter focal length the dispersion in the second or third order of the grating is amply sufficient for the present purpose.

If all of the doublets observed in spot spectra could be photographed in the laboratory it would be easy to make a satisfactory comparison. Unfortunately, however, most of these lines are very faint in the spark, and as the great majority of them occur in the less refrangible part of the spectrum, exposures of from fifteen to twenty hours are sometimes required to bring out even the stronger doublets. The results hitherto obtained for the iron doublets are

[a] Hale, "The Pasadena Laboratory of the Mount Wilson Solar Observatory," Contributions from the Mount Wilson Solar Observatory, No. 27; Astrophysical Journal, Vol. XXVIII, p. 244, 1908.

brought together in the following table. I am indebted to Mr. Adams for these measures and for many of the others given in this paper. Miss Burwell and Miss Wickham have also assisted in the measurement of the spot and spark photographs.

TABLE I.—*Iron doublets.*

Wave length.	$\Delta\lambda$, spark.	$\frac{\Delta\lambda, \text{spark.}}{5.1.}$	$\Delta\lambda$, spot.	δ.	$\frac{\Delta\lambda, \text{spark.}}{\Delta\lambda, \text{spot.}}$
6213.14	0.703	0.138	0.136	−0.002	5.2
6301.72	.737	.144	.138	− .006	5.3
6302.71	1.230	.241	.252	+ .011	4.9
6337.05	0.895	.175	.172	− .003	5.2

The first column gives the wave length of the doublet; the second, the separation in Ångströms of the components, observed along the lines of force in a field of about 15,000 gausses;[a] the third, the quantity given in column 2 divided by 5.1; the fourth, the separation of the components observed in the spot spectrum; the fifth, the residuals obtained by subtracting the quantities in the third column from those in the fourth; the last column gives the ratio of the separation in the spark, for a field of about 15,000 gausses, to the observed separation in the spot. The mean value of this ratio, 5.1, gives an approximate measure of the strength of the field in spots, which comes out about 2,900 gausses.

The agreement between the spot and laboratory results is so close that it can hardly be the result of chance. But when we come to the case of titanium, observed in the laboratory in a field of about 12,500 gausses, we find a very different condition of affairs.

TABLE II.—*Titanium doublets.*

Wave length.	$\Delta\lambda$, spark.	$\frac{\Delta\lambda, \text{spark.}}{5.1.}$	$\Delta\lambda$, spot.	δ.	$\frac{\Delta\lambda, \text{spark.}}{\Delta\lambda, \text{spot.}}$
5903.56	0.732	0.144	0.086	−0.058	8.5
5938.04	.737	.145	.080	− .065	9.2
6064.85	.876	.172	.184	+ .012	4.8
6303.98	.493	.097	.093	− .004	5.3
6312.46	.615	.121	.091	− .030	6.8

If we use the factor 5.1 employed in the case of iron, we find that two of these doublets, λ 6064.85 and λ 6303.98, agree closely in spot and spark. In some of our spot photographs λ 6064.85 appears to be a triplet, though the components are not clearly separated. With the rhomb and Nicol a faint central component persists when either the red or the violet component is cut off. It is possible that this central line is due to some substance other than titanium in the spot, but it is certainly very nearly in the position of the solar titanium line[b] λ 6312.46 gives a residual of 0.03 Ångströms, which exceeds the error

[a] This value of the field strength may be in error by 1,000 gausses, because of the disturbing effect of the iron electrodes.

[b] It is conceivable that under conditions analogous to those that give rise to the H_3 and K_3 lines, a doublet might be produced within the strong magnetic field of the spot, and a single line, at the center of the doublet, by the absorption of the vapor at a high level, where the field strength is low.

of measurement. The other doublets, λ 5903.56 and λ 5938.04, show in the spot spectrum but little more than one-half the separation that would be expected on the assumption that the strength of the field is the same for all of these lines.

On consideration it will be seen, however, that the separation of the doublets must depend, in some degree, on the distribution of the absorbing vapor in the solar atmosphere, and on the coefficient of absorption of the particular line employed. A striking instance of this kind, affecting lines of the same series, is illustrated in the case of hydrogen, described in a previous paper.[a] Although the Hδ line extends to the upper part of the chromosphere and prominences, the mean level represented by its absorption is much lower than that given by Hα. The consequence is that Hα enables us to photograph the solar vortices, the characteristic stream lines of which do not appear at the lower Hδ level. Similarly, if the intensity of a given titanium line falls off rapidly, the level represented by this line may be comparatively low. If, on the other hand, its intensity curve is of such a form as to indicate that the absorption at higher elevations plays an important part, the mean level represented by the line may be considerably higher than in the previous case. To settle this question we must know: (1) The range of elevation in the spot of the vapors of iron, titanium, and other elements; (2) the intensities of the lines of these elements at different levels; (3) the rate at which the strength of the field decreases upward.

In the absence of information regarding the first two points, we may inquire as to the probable relative behavior of titanium, iron, and other elements if the distribution of the vapors at different levels were the same as in the chromosphere. From a discussion of a large number of photographs of the flash spectrum, made by different observers at several eclipses, Jewell has compiled a table showing the heights above the sun's limb attained by various lines in the blue and violet.[b] The heights for titanium range from 100 miles (160 kilometers) for λ 4466.0 to 3,500 miles (5,640 kilometers) for λ 4466.7, while certain strong enhanced lines in the ultra-violet reach elevations of 6,000 or 8,000 miles (9,660 or 12,880 kilometers). For iron the minimum height is 200 miles (320 kilometers) for λ 4482.4 and the maximum 1,000 miles (1,610 kilometers) for λ 4584.0. Chromium ranges from 100 miles for λ 4280.2 to 1,200 miles (1,930 kilometers) for λ 4275.0; manganese from "100 miles or more" for λ 4451.8 to "800 miles (1,290 kilometers) or more" for λ 4030.9; vanadium from 100 miles for λ 4390.1 to 200 miles for λ4379.4. It thus appears that the range in level represented by the titanium lines is much greater than for the lines of iron, chromium, manganese, and vanadium. If the vapors were similarly distributed in spots, the maximum strength of field indicated by the titanium lines should therefore correspond with the maximum value for iron, but some titanium lines, produced by absorption at higher mean levels, should give lower field strengths. Chromium should agree more nearly with iron. Vanadium, if the less refrangible lines reach no greater elevations, should give closely accordant (maximum) values for the field strength. It will perhaps be possible, with the aid of the 30-foot spectrograph, to determine the relative levels in the chromosphere attained by most of the lines in question, but it is a much more difficult matter to do this for sun spots. I hope, however, that our new spectroheliograph of 30 feet focal length may throw some light on this subject.

It is evident that these considerations will have no bearing on the present problem, unless the field strength decreases very rapidly upward in spots.

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[a] Solar Vortices, p. 3.

[b] "Total Solar Eclipses of May 28, 1900, and May 17, 1901." Publications of the United States Naval Observatory, second series, Vol. IV, Appendix I.

That this probably occurs is shown by the fact that the D lines of sodium and the *b* lines of magnesium are usually but slightly affected in the spot spectrum,[a] and are displaced through a very small distance when the Nicol is rotated. Thus, at the level represented by these lines, which attain elevations in the chromosphere probably not exceeding 5,000 miles, the field strength is reduced to a small fraction of its maximum value.

The following doublets have been measured in the spectrum of chromium:

TABLE III.—*Chromium doublets.*

Wave length.	$\Delta\lambda$, spark.	$\frac{\Delta\lambda, \text{spark.}}{4.9.}$	$\Delta\lambda$, spot.	δ.	$\frac{\Delta\lambda, \text{spark.}}{\Delta\lambda, \text{spot.}}$
5304.36	0.636	0.130	0.188	+0.058	3.4
5387.16	.676	.138	.085	− .043	8.0
5713.00	.610	.124	.161	+ .037	3.7
5781.40	.755	.154	.121	− .033	6.2
5781.97	.922	.188	.212	+ .024	4.3
5783.29	.772	.158	.137	− .021	5.6
5784.08	.720	.147	.121	− .026	6.0
5785.19	.707	.144	.137	− .007	5.1

In photographing these lines in the spark the strength of the field was 12,500 gausses. The strength of the field in spots, as indicated by the mean separation of the chromium doublets, is therefore 2,600 gausses. * * *

SIGN OF THE CHARGE THAT PRODUCES THE FIELD IN SUN SPOTS.

If the evidence presented in this paper renders probable the existence of a magnetic field in sun spots, it is of interest to inquire concerning the sign of the charge which, according to our hypothesis, produces the field. * * *

In the case of the solar vortices we have to consider two sets of charged particles, which may be entirely distinct from one another: (1) those whose vibrations give rise to the lines in the spectra of spots, and (2) those that carry the charge which, by the hypothesis, produces the magnetic field. The Zeeman effect supplies the means of determining the direction of the lines of force of the sun-spot fields, and photographs of the vortices, made with the spectroheliograph, indicate the direction of revolution of the particles. Thus we are in a position to determine the sign of the charge carried by the particles which produce the fields. As pointed out independently by König and Cornu, the violet component of a magnetic doublet observed along the lines of force is formed by circular vibrations, having the direction of the current flowing through the coils of the magnet.[b] From observations of circularly polarized light, made in our Mount Wilson laboratory by Doctor St. John and confirmed by myself, it appears that when the Nicol prism of the tower spectrograph stands at 60° E. it transmits the violet component of a doublet produced in a magnetic field directed toward the observer. From Biot and Savart's law the direction of the current causing such a field is counter-clockwise, as seen by the observer. In the same position the Nicol also transmits the violet component of a doublet

[a] Except for the strengthening of the wings, which may be produced by some cause other than a magnetic field.

[b] See Cotton, Le phénomène de Zeeman, chap. vii, König. Wied. Ann. Vol. 62, p. 240, 1897.

produced in a sun spot surrounded by a vortex in which the direction of revolution is clockwise. As a negative charge revolving clockwise produces a field of the same polarity as an electric current flowing counter-clockwise, we may conclude that the magnetic field in spots is caused by the motion of negative corpuscles.

PROBABLE SOURCE OF THE NEGATIVE CORPUSCLES.

We may now consider the probable source of a sufficient number of negative corpuscles to produce a field of about 2,900 gausses in sun spots.

In his *Conduction of Electricity through Gases* (p. 164) J. J. Thomson writes as follows:

"We thus are led to the conclusion that from an incandescent metal or glowing piece of carbon 'corpuscles' are projected, and though we have as yet no exact measurements for carbon, the rate of emission must, by comparison with the known much smaller rate for platinum, amount in the case of a carbon filament at its highest point of incandescence to a current equal to several ampères per square centimeter of surface. This fact may have an important application to some cosmical phenomena, since, according to the generally received opinion, the photosphere of the sun contains large quantities of glowing carbon; this carbon will emit corpuscles unless the sun by the loss of its corpuscles at an earlier stage has acquired such a large charge of positive electricity that the attraction of this is sufficient to prevent the negatively electrified particles from getting right away from the sun; yet even in this case, if the temperature were from any cause to rise above its average value, corpuscles would stream away from the sun into the surrounding space."

On another page (168) Thomson also remarks: "The emission of the negative corpuscles from heated substances is not, I think, confined to the solid state, but is a property of the atom in whatever state of physical aggregation it may occur, including the gaseous." After illustrating this in the case of sodium vapor, Thomson adds (p. 168):

"The emission of the negatively electrified corpuscles from sodium atoms is conspicuous, as it occurs at an exceptionally low temperature. That this emission occurs in other cases, although at very much higher temperatures, is, I think, shown by the conductivity of very hot gases (or at any rate by that part of it which is not due to ionization occurring at the surface of glowing metals), and especially by the very high velocity possessed by the negative ions in the case of these gases. The emission of negatively electrified corpuscles from atoms at a very high temperature is thus a property of a very large number of elements, possibly of all."

Thus the chromosphere, as well as the photosphere, may be regarded as copious sources of negatively electrified corpuscles. The part played by these corpuscles in sun spots can not be advantageously discussed until the nature of the vortices is better understood.[a] At present it is enough to recognize that the supply of negative electricity appears amply sufficient to account for the magnetic fields. * * *

EXTERNAL FIELD OF SUN SPOTS.

We have already seen that the strength of the field in spots apparently changes very rapidly along a solar radius, and is small at the upper level of the chromosphere.

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[a] For this reason a discussion of the very interesting suggestion of Prof. E. F. Nichols, that the positively and negatively charged particles are separated by centrifugal action in the spot vortex, is reserved for a subsequent paper.

If subsequent work proves this to be the case, it will appear very improbable (as indicated by theory) that terrestrial magnetic storms are caused by the direct effect of the magnetic fields in sun spots. We have some reason to think that their origin may be sought with more hope of success in the eruptions shown on spectroheliograph plates in the regions surrounding spots. * * *

MOUNT WILSON SOLAR OBSERVATORY,
October 7, 1908.

ADDENDUM.

The fact that the doublets in the sun-spot spectrum do not change to triplets, even when the spot is as much as 60° from the center of the sun, appeared, when the proof of the above paper was corrected, to be a serious argument against the magnetic field hypothesis. Thanks to the recent work of Doctor King, this difficulty no longer exists, at least in the case of several iron and titanium lines. Photographs of the spark spectrum in a strong magnetic field, taken at right angles to the lines of force, show that the iron lines λλ6213.14, 6301.72, and 6337.05 are doublets, with no trace of a central component. As these lines are also doublets when observed parallel to the lines of force, it is only natural that they should be double in spots, wherever situated on the solar disk. λ6173.55, which is a fine triplet in spots, is a triplet when observed at right angles to the lines of force. But the line λ6302.71 is the most interesting of all. In Table I this is classed as a spot doublet. In the spot spectrum the line appears as a triplet, but so decidedly asymmetrical that I supposed the intermediate line to be due to some element other than iron, greatly strengthened in the spot. It now turns out, however, that this is an asymmetrical triplet in the spark, when observed at right angles to the lines of force. Moreover, the displacement of the intermediate line from the center is toward the red, both in the spot and in the spark. As soon as a suitable photograph can be taken in a higher order of the grating, it will be possible to measure the asymmetry in the spark, as has already been done in the spot spectrum.

The titanium lines λλ6303.98 and 6312.46, which are double in spots, are also double in the spark, when observed at right angles to the lines of force. λ6064.85, already mentioned as a triplet in spots, with a rather faint central component, is a triplet, with strong central component, in the spark under the above conditions.

The titanium spot doublets λλ5903.56 and 5938.04 (Table II) have not yet been observed at right angles to the lines of force.

These results leave no doubt in my mind that the doublets and triplets in the sun-spot spectrum are actually due to a magnetic field. As I am now designing a spectrograph of 75 feet (23 meters) focal length, for use with a tower telescope of 150 feet (46 meters) focal length, I hope it may become possible to investigate small spots, as well as large ones, and to resolve many of the close doublets and triplets in their spectra.

Let us sum up the principal parts of Mr. Hale's experimental evidence: (1) That some spectrum lines which are single in the ordinary solar spectrum become double in sun spots; (2) that these double lines are found to be circularly polarized in opposite directions; (3) that, as shown by Zeeman, this is a characteristic of spectrum lines produced in a powerful magnetic field and observed along the magnetic lines of force; (4) that the different doublets in

the spots in most cases have almost exactly the same relative separations as have the corresponding lines when observed in the laboratory in a magnetic field; (5) that lines found double in spots near the sun's limb are also found double when observed in the laboratory at right angles to a magnetic field; (6) that, as shown by Rowland, electric charges in revolution produce a magnetic field; (7) that, as shown by Thomson, it is probable that electrically charged bodies or ions are numerous in the sun; (8) that the spectroheliograph has shown immense spiral configurations suggesting vortices in the higher solar layers and that these vortices are unmistakably connected with sun spots; (9) that the vortices are some right handed and others left handed; (10) that in sun spots surrounded by right-handed vortices the polarization of the components of the spectrum doublets is always found opposite to that for sun spots with left-handed vortices. In view of all this it must be admitted that the existence of magnetic fields in the neighborhood of sun spots is beyond reasonable question, and Mr. Hale's explanations of them as due to the revolution of electrical charges in vortices have strong support. At the same time it must be kept in mind that the vortical motions are inferred rather than demonstrated, and inferred only for high levels, presumably above the levels of sun spots. Furthermore, spectra of spots near the sun's limb do not reveal evidence of motion such as would be expected if vortices exist in the spots themselves. Further evidence must therefore be awaited before fully accepting the vortex theory of the production of the magnetic fields which Mr. Hale has discovered.

A possible application to terrestrial affairs of this new discovery of magnetism in sun spots springs at once into mind, but according to Mr. Hale's view the evidence at present is opposed to the conclusion that the magnetic fields found in sun spots can produce appreciable effects on the earth. Nevertheless, it will be almost a matter of regret if further study shall not indicate that the magnetic sun-spot fields are competent to produce the disturbances of terrestrial magnetism which for many years have been known to be intimately related to the prevalence of sun spots.

CLIMATIC VARIATIONS: THEIR EXTENT AND CAUSES.[a]

By Prof. J. W. Gregory, F. R. S.
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Introduction.

The past variation of climate is an attractive study, as it controls so many questions in geology, geography, and meteorology. But the subject is of especial difficulty, as it deals with the action of complex chemical and physical processes working under conditions and on materials which can be estimated only by the freest speculation. The question may be approached a priori by consideration of the evolution of the atmosphere, as suggested by general chemical probabilities; or we may determine from the sedimentary rocks the strength and nature of the geographical agencies that formed them; or we may examine the indirect evidence given by fossils as to the climates under which they lived. The fact of marked local variations in climate is abundantly proved; and it will probably be equally agreed that there is no evidence known to the geologist of any progressive refrigeration of the earth. The idea of the secular cooling of the earth is deeply impressed on our terminology; but geological principles are independent of the theory. The terms suggested by it may always be retained from their historic interest and convenience, as we still speak of the rising of the sun. Responsibility for the belief in the secular cooling of the earth rests with the astronomers and physicists, from whom geologists have accepted it.

Local variations in climates are abundantly established by the former glaciation of temperate regions, the once greater extension of glaciers in tropical regions, and the frequent growth of reef-building corals outside their present geographical limits. But we need not unnecessarily increase the difficulties of the problem by accepting the world-wide range of great climatic changes without convincing evidence. Doctor Ekholm takes as the starting point of his valuable paper the ground that "the inquiries of modern geology

[a] Reprinted by permission from Congrès Géologique International. Compte Rendu de la dixième session, Mexico, 1906. Mexico City, 1907, pp. 407–426. (Printer's proofs not seen by author.)

unanimously indicate that all great climatic changes have occurred simultaneously on the whole earth."[a]

But geological opinion is by no means unanimous on this question, that the major climatic variations were world-wide in their influence. The amplest evidence in support of the view that a colder climate was once universal is supplied by the Pleistocene glaciations; and it is certain that at one part or another of the Pleistocene period the glaciers of many distant parts of the world were much larger, and that wide areas in the north temperate zone were overwhelmed by glacial conditions. But there appears to be a steadily growing opinion that the glaciers of the different glacial centers did not attain their greatest development at the same time. Thus, the glaciation of Greenland is now at its maximum; at an earlier period of the Pleistocene Labrador was covered by an ice sheet, which dwindled as that of Greenland developed; and the glaciation of the Canadian Rocky Mountains was probably still earlier than that of Labrador. Similarly in Europe the conditions of preservation and general aspect of the glacial deposits suggest that the culmination of the Norwegian glaciation was somewhat later than that of the British Isles.

The General Uniformity of Climates in the Past.

The first striking fact in the geological history of climate is that the present climate of the world has been maintained since the date of the earliest, unaltered, sedimentary deposits. The oldest sandstones of the Scotch Highlands and the English Longmynds show that in pre-Cambrian times the winds had the same strength, the raindrops were of the same size, and they fell with the same force as at the present day. The evidence of paleontology proves that the climatic zones of the earth have been concentric with the poles as far back as its records go; the salts deposited by the evaporation of early Paleozoic lagoons show that the oldest seas contained the same materials in solution as the modern oceans; and glaciations have recurred in Arctic and, under special geographical conditions, also in temperate regions at various periods throughout geological time.

The mean climate of the world has been fairly constant, though there have been local variations which have led to the development of glaciers in regions now ice free, at various points in the geological scale. That there has been no progressive chilling of the earth since the date of the oldest known sedimentary rocks is shown by their lithological characters and by the recurrence of glacial deposits, some of which were laid down at low levels at intervals throughout geolog-

[a] Dr. Nils Ekholm, "On the variations of the climate of the geological and historical past and their causes," Quart. Journ. Roy. Met. Soc., Vol. XXVII, 1901, p. 3.

ical time. Thus remnants of a series of glacial deposits, which are probably pre-Cambrian, occur in a series of localities around the Arctic Zone;[a] fragments of this early, circum-Arctic glacial chain occur in the north of Norway, as described by Reusch and Strahan;[b] in Spitsbergen;[c] as some bowlder beds, the descriptions of which are suggestive of glacial formation, on the Coppermine River, and in Labrador, where, however, according to A. P. Low, they may be Cambrian; and finally on the northern coasts of Siberia, near the estuary of the Lena. The Cambrian system contains an extensive series of glacial deposits, discovered by Mr. Howchin,[d] running north and south through South Australia, between the latitudes of 32° and 35° S., and as these Cambrian till are interstratified with marine rocks, they were probably formed about sea level.

The next proved glacial period is the Upper Carboniferous and perhaps Permian, as proved by the glacial deposits of India, South Africa, Australia, and South America. They were originally assigned, in Africa and Australia, to the Trias, and subsequently to the Permian, and the Permian age of the South Africa glacial deposits is still asserted by some geologists. But, according to Mr. Seward,[e] the glacial deposits at Vereniging—which, according to one theory, are redeposited glacial material, and would, therefore, be the latest of the South African glacial beds—are Upper Carboniferous, and that is the age of the best known and most extensive of the glacial deposits of southeastern Australia. The Upper Cretaceous has some evidence of glaciation in the Northern Hemisphere, for the occurrence of drift ice is the most probable explanation of the bowlders found in the British Chalk; and Professor Garwood found a glaciated pebble on Bunting Bluff, in Spitsbergen, in some conglomerates which are Upper Cretaceous or Lower Cenozoic.[f] With the exception of such scraps of evidence, there is no convincing proof of low level glacial action until we reach the Pleistocene.

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[a] J. W. Gregory, Quart. Journ. Geol. Soc., Vol. LIII, 1897, p. 155.

[b] A. Strahan, "The raised beaches and glacial deposits of Varanger Fiord," ibid., Vol. LIII, 1897, pp. 147–153.

[c] The pre-Cambrian glacial bed in Spitsbergen was referred to by Nordenskjold. I accidentally rediscovered it at Fox Point, on Bell Sound, in 1896, and sketched the best exposed section. (Quart. Journ. Geol. Soc., Vol. LIV, 1898, p. 216.)

[d] Brief reference to these Cambrian glacial deposits is given in Mr. W. Howchin's paper, "The geology of the Mount Lofty ranges," Pt. I, Trans. Roy. Soc. South Australia, Vol. XXVIII, 1904, pp. 259, 278, and Pl. XLIII.

[e] A. C. Seward, "Fossil floras of Cape Colony," Annals South Africa Museum, Vol. IV, Pt. I, 1903, p. 101.

[f] Quart. Journ. Geol. Soc., Vol. LIV, 1898, p. 217.

Exaggerated Estimates of Climatic Changes.

The range of climatic variations in the past has been often greatly exaggerated, thereby leading to the apparent necessity for revolutionary changes in former meteorological conditions. But the climatic changes we have to explain appear to have been either local in area or moderate in degree.

The opinion that there have been fundamental changes in climate is based mainly upon the evidence of former glaciations and on the supposed existence of tropical climates in the arctic regions. That tropical or subtropical conditions once prevailed in the Arctic Circle is affirmed on the reported occurrence there of fossil coral reefs and tropical vegetation. I have previously quoted evidence to show that this view is greatly exaggerated.[a] One notice of that paper described its views as "très hardie," but I am not aware of any refutation of its conclusions. The idea of the former tropical condition of Greenland is still confidently asserted. Thus Doctor Ekholm[b] refers to the nearly tropical climate that prevailed in the arctic regions during the Cretaceous age, when he estimates that the mean temperature was 36° F. higher than during the Pleistocene. But so far as I know the evidence there is no proof that the arctic regions ever had a subtropical or even a warm, temperate climate.

THE EVIDENCE OF FOSSIL CORALS.

The Arctic Ocean has been described as having been a coral sea in Silurian and Carboniferous times. This view led to Blandet's suggestion—well known by its advocacy by Sir John Murray—that in Paleozoic times light and heat were equally distributed throughout the world; and also to the theories that the heat from the sun is diminishing owing to the smaller size of the sun, as suggested by Helmholtz, or to its lower intensity, as advocated by Dubois. But the fossil faunas of the arctic seas all show the dwarfing effect of unfavorable conditions when compared to the contemporary faunas in the seas to the south.

Corals of reef-building genera have lived in the arctic regions; but I have seen no arctic specimens larger than nodules which could have grown in a cool sea. The asserted existence of arctic coral reefs in Silurian times was based on a collection made in Grinnell Land, which is now in the British Museum. But the specimens show nothing more than the growth of small nodular corals, such as may have grown in a temperate sea. Paleozoic corals have also been found in the Timan-Urals and in the Silurian rocks of the New Siberian

[a] "Some problems of Arctic Geology. II. Former arctic climates."
[b] Ekholm; op. cit., pp. 25, 26.

Islands; but in both cases the evidence shows that the coral faunas were stunted in comparison with those of the contemporary seas to the south. Numerous simple and simply branched corals, associated with thick growths of calcareous algæ, grow to-day in the northern seas. Dead branches of Lophohelia are so common on one bank in the Christiania Sound (latitude 58° N.) that it has been described as a Pleistocene coral reef. Small nodules of corals, of reef-building genera, such as *Plesiastræa*, live at present in the cold seas of southern Australia, far to the south of the region of coral reefs.

Hence I feel justified in repeating the view expressed in 1897, that the evidence of the fossil corals from the Silurian rocks of Greenland and Great Britain shows "that there was almost as great a difference between the temperature of the sea in the areas as there is to-day."[a]

The evidence of the fossil corals is supported by that of the arctic marine faunas of all geological periods. Their most striking characteristics in the past are their characteristics of to-day, and show "that all through geological time the northern faunas have lived under the blight of arctic barrenness."[b]

THE EVIDENCE OF THE FOSSIL FLORAS.

The fossil floras of the Arctic, as identified by Heer, have been used as the basis of the attractively sensational theory that Greenland enjoyed a tropical climate in Miocene times and a tropical or subtropical climate in Cretaceous times. But the evidence so far adduced appears to be quite insufficient to justify this view. The most characteristically tropical of the plants claimed to occur in Greenland are the palms; but the fossil arctic palms have now been dismissed as based on erroneous identifications. Much weight has also been attached to some fossil tree ferns of the genus *Dicksonia*, from the Cretaceous of Greenland. But the best-known living species of that genus is *Dicksonia antarctica*, which occurs in southern New Zealand; and *Dicksonia* also lives on the high "Snowy Plains" of the Victorian Highlands, where it is sometimes buried under snow for four or five months in the year. Hence the existence of fossil tree ferns, especially of the genus *Dicksonia*, would certainly not imply tropical conditions. Heer's identifications have been contemptuously rejected by many later botanists, including Dr. Robert Brown, Dr. Starkie Gardner, and Professor Nathorst. Most of Heer's determinations were based upon leaves, which give no data for generic identification. Nor does the existence of leaf beds in the Arctic prove anything more than local geographical changes, for leaves grow with remarkable rapidity and luxuriance within the Arctic Circle, under the influence of the

[a] Op. cit., Nature, Vol. LVI, 1897, p. 352.
[b] Ibid., p. 352.

continuous daylight of summer. That dense foliage grows upon the moraines of Alaska is well known from the photographs, taken upon the Malaspina Glacier, published by I. C. Russell;[a] and in the same district forests of fir trees, growing on moraines, are being now transported by the Alaskan glaciers.

The fossil tree trunks in arctic coal seams would supply better evidence of a change of climate than the fossil leaves, if there were evidence to prove that the trees had grown in situ. The view that the three months' darkness of winter would be fatal to tree growth is now recognized as untenable; but it is a fact that forests do not occur north of 70°, although fossil tree trunks have been found beyond that latitude. But these tree trunks were probably carried north as drift-wood.

Robert Brown has described the Disco plant beds and come to the definite conclusion that the plants had not grown in situ. Baron von Tol has published photographs of plant beds associated with ancient ice in northern Siberia, but his photographs show the roots of nothing larger than shrubs. In 1896 I had occasion to mine some hundredweights of coal from the seam of Advent Bay, Spitsbergen (latitude 78° 15′ N.), and the section exposed gave no evidence that the coal had been formed from vegetation that had grown in situ.

In many places the arctic shores are white with a litter of pine, fir, and larch logs, which have been floated down the Siberian rivers, drifted across the Arctic Ocean, and been thrown upon the shores.[b] These accumulations of driftwood become covered by the growth of moss, saxifrages, and arctic willows; and if then buried beneath sheets of sediment would form arctic coal seams, made from timber that had grown in central Asia.

The paleobotanical evidence that the arctic regions had a tropical or subtropical climate in the Cretaceous is inadequate, and it is contradicted by the Paleozoological evidence of the contemporary marine deposits. The Cretaceous marine beds in Greenland have a stunted fauna, which has no tropical or subtropical characters. The British Chalk sea was sufficiently cold for drift ice to carry bowlders as far south as London and its fauna is decidedly nontropical. The Chalk sea was of moderate depth, but its crinoids were small and scarce, its corals were small and simple, and its mollusca indicate a cooler sea than do the *Hippurites*, etc., of the Mediterranean beds. In the Lower Cretaceous beds of British Isles there are abundant shallow sea and shore deposits, but there are no coral reefs, and the general aspect of the fauna indicates a sea decidedly colder than that of the

[a] I. C. Russell, "Second expedition to Mount St. Elias," Thirteenth Ann. Rep. U. S. Geol. Surv., 1893, Pl. XIV.

[b] A photograph showing one of these timber-strewn beaches has been published in the "Voyage de la Manche," Pl. V, 1894.

Jurassic. The British Cretaceous marine deposits indicate the prevalence of a cool temperate, and those of Greenland an arctic, climate, in the period when, on the unreliable evidence of fossil leaves, we are asked to believe the conditions in Greenland were tropical or subtropical.

The paleontological evidence at present available does not throw on us the burden of explaining why the Arctic had a tropical climate, for it simply contradicts assertion as a matter of fact.

Glaciation Due to Local Climatic Variations.

The second line of evidence used to prove intense, widespread climatic changes is the occurrence of glacial deposits in the temperate zones and the greater extensions of tropical glaciers. But this evidence has also been used to indicate more extreme changes than are necessary to explain the facts. Thus, it appears to be sometimes considered that the glacial beds of South Africa, India, and Australia prove that in one epoch of the Upper Paleozoic the whole area of the Indian Ocean, from 30° N. latitude in India to more than 40° S. in Tasmania was undergoing glaciation.

The difficulty of explaining former glaciations has been greatly increased by such assumptions as that they were due to the development of a severer climate at the same time throughout the world.

There is not yet adequate evidence that the former glaciations were accompanied by a universal change of climate. It is true that there is evidence of a more extensive Pleistocene glaciation in many regions of the world, including Mount Kenya, upon the equator in British East Africa, Mount Kosciusko in southeastern Australia, western Tasmania, the South Island of New Zealand, Patagonia, and a belt practically all across the temperate regions of the Northern Hemisphere. Accordingly it is claimed, as by Ekholm (op. cit., p. 31), that the snow line was everywhere 1,000 meters lower at the time when Europe had its "Great Ice Age." But there are too many cases in which evidence of such former extension has been sought for in vain, for a universal lowering of temperature in the Pleistocene to be accepted as yet finally established. In the North Island of New Zealand there is no evidence of any former glaciation, and had its existing snowfields extended more than 3,000 feet lower, they should have left some traces of so great growth. D'Orbigny and Whymper both failed to find any evidence of any greater extension of the existing glaciers on the equatorial Andes than could be explained by a local variation in the winds. In equatorial Africa no Pleistocene glacial deposits have been found, except on the dwindling summits of the highest mountains; and the coastal raised beaches give no evidence of any contemporary reduction in the temperature of the

adjacent seas. There is no evidence of any Pleistocene glaciation on the mainland of Australia, except on the highest summit of the Australian Alps; and though Mount Kosciusko, which is now 7,256 feet above sea level, in a region with a 60-inch rainfall, had once a few small glaciers, there is no evidence in Australia generally of a colder Pleistocene climate. In fact the early Pleistocene or Pliocene fauna of central Australia indicates the extension then of the tropical fauna of northern Australia into the temperate regions of the Continent. Neither the flora nor fauna of the Pleistocene deposits of Victoria indicates a colder climate than that of the present time.

The glaciations themselves, moreover, though often very extensive, appear to have been always local. Thus those of the Pleistocene in the Northern Hemisphere were grouped around a series of centers, which are not always in particularly high latitudes. In North America there appear to have been three glacial centers, that of the Canadian Rocky Mountains in latitude 55° to 60°; that of eastern Canada in latitude 50° to 55°, and with its southern edge extending to latitude 42° N.; and that of Greenland of which the center is from 70° to 75° N.

In Europe the glaciation of the British Isles extended as far south as latitude 52°; that of Scandinavia, from a center between latitude 60° and 65° N., overrode the country as far south as northern Germany in latitude 53° N.; and the other centers farther south developed where high mountains, such as the Alps, occurred near warm seas.

Causes of Climatic Variations.

If it be accepted that former climatic changes involve less extreme changes of temperature than have been generally assumed, and that we are not called on to explain former tropical forests in the arctic lands, or fossil coral reefs in the arctic seas, or occasional universal refrigerations of the earth, then the problem of climatic variations is greatly simplified.

The Elevation Theory.

Several explanations, attractive from their simplicity, may then be at once dismissed. The theory of the migrations of the poles into temperate regions, although supported by Oldham and Penck for the Upper Paleozoic glaciation, is contradicted by the evidence of paleontology; and the explanations it would give of world-wide changes are not required. The once popular theory that ice caps have been produced by the greater elevation of the land may be abandoned, as opposed to meteorological principles, and as implying a reversal of the facts, glaciations having so often accompanied periods of greater submergence of the land, and milder climates having coin-

cided with periods of emergence; and it would be quite inapplicable to the Upper Paleozoic glaciation of Australia, of which the glacial deposits were in places submarine.

THE OBLIQUITY OF THE ECLIPTIC.

Nor, in spite of the fresh use made of it by Ekholm and Dickson, does the variation in the obliquity of the ecliptic appear to help materially; for all the influences of this agency are open to the fundamental objection that variations in obliquity recur at what, geologically speaking, are short and frequent intervals; whereas ancient glaciations happened but seldom, and were apparently irregular in their time of return.

VARIATIONS IN THE CARBONIC ACID CONTENT OF THE ATMOSPHERE.

The view that now seems most popular explains the major climatic changes by variations in the powers of selective absorption of heat by the atmosphere. The change is attributed either to variations in the amount of aqueous vapor as urged by de Marchi[a] or of carbon dioxide as advocated by Svante Arrhenius,[b] and recommended to us by the brilliant advocacy and high authority of Prof. T. C. Chamberlin.[c]

The aqueous vapor theory has been adequately disposed of by Arrhenius, whose alternative is especially attractive, as it demands comparatively small differences of temperature and very modest variations in the amount of carbonic acid. Thus he calculates that an increase of the carbonic acid from 0.03 to 0.09 per cent would give the polar regions a temperate climate, by a rise of from 12° to 16° F. Nevertheless, this theory—that former colder periods were due to a reduction of the carbonic acid in the air and warm periods to an increase in its amount—is faced by objections which I venture to think still inadequately answered.

No one is likely to deny the possibility of great variations in the former composition of our atmosphere. The theories of Koene (1856), Phipson (1893–94), or Stevenson (1902),[d] that the primitive

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[a] De Marchi, "Le Cause dell'era Glaciale," Pavia, 1895.

[b] S. Arrhenius, "On the influence of carbonic acid in the air upon the temperature of the ground," Phil. Mag., ser. 5, Vol. XLI, 1896, pp. 237–276.

[c] T. C. Chamberlin, "A group of hypotheses bearing on climatic changes," Journ. Geol., Vol. V, 1897, pp. 676–683; "The influence of great epochs of limestone formation upon the constitution of the atmosphere," ibid., Vol. VI, 1898, pp. 609–621.

[d] J. Stevenson, "The chemical and geological history of the atmosphere," Phil. Mag., ser. 5, Vol. L, pp. 312–323, 399–407; also Pt. II, "The composition and extent of the atmosphere in very primitive times," Phil. Mag., ser. 6, Vol. IV, 1902, pp. 448–451.

atmosphere was many times larger than at present, was rich in carbonic acid, and had no free oxygen, may be inapplicable to any part of geological time; though they may very likely be true for the first formed atmosphere, long before the date of the oldest known sedimentary rocks. From the earth's surface we look up through zones of atmosphere, in which the oxygen and carbonic acid steadily diminish, and the minute proportion of hydrogen at sea level increases, until 50 miles high the air consists practically of hydrogen alone.[a] The aurora flares above us in a mixture of hydrogen and neon; and as there is evidence of such fundamental variations in the atmosphere in space, there may well have been marked changes in time. There are so many agents pouring carbonic acid into the air and so many others withdrawing it that it would be strange if the present equilibrium had always been maintained.

The oceanic control.

Nevertheless it must not be forgotten that the ocean, as shown by Schloesing,[b] supported by the weighty experiments of Dittmar, controls the amount of carbonic acid in the atmosphere. If the amount of carbonic acid in the atmosphere is diminished, the bicarbonates in the sea are dissociated; the gas thus liberated is poured into the air until the former equilibrium between the tension of the carbonic acid in the atmosphere and in the sea is reestablished. Hence, a reduction of carbonic acid in the air is automatically followed by the discharge of nearly as large a quantity from the sea; so that any reduction is distributed between the air and the ocean. Any increase of carbonic acid in the atmosphere is followed by the reverse change, and only one-sixth of the amount poured into the atmosphere is retained there. It is true that great variations in the relative extent of sea and land would affect the dissociation pressure of the bicarbonates in the sea, but it would require a great reduction in the area of sea surface to affect the equilibrium appreciably.

Possible evidence from paleontology.

Efforts may be made to ascertain from paleontological evidence whether the atmosphere has recently altered its composition. This line of inquiry does not promise reliable conclusions, owing to the powers of adaptation of both animals and plants to changes in the atmosphere. An increase in carbonic acid, provided it be not accom-

[a] Sir J. D. Dewar, "The problems of the atmosphere," Proc. Roy. Inst., Vol. XVII, 1902, p. 226.

[b] Schloesing, "Sur la constance de la proportion d'acide carbonique dans l'air," Compt. Rend., Vol. 90, 1880, p. 140.

panied by organic solution, from 3 parts to 100 parts in 10,000—an increase ten times as great as the maximum considered by Arrhenius—is inappreciable to man. The ordinary data of mine ventilation and the experimental results of Dr. J. S. Haldane and Dr. Lorraine Smith show that men can stand, without serious inconvenience, an increase of carbonic acid to even 400 parts in the 10,000; and as there is no probability of temporary variations to any such degree, a slow increase in the carbonic acid contents of the air would probably have a greater indirect effect upon animals through its action on the temperature than by its direct effect on respiration.

Noncoincidence of dates.

The main objection to the atmospheric variation theory is that it does not explain the facts of historical geology. And geologists, as the historians of the earth, test theories whenever possible, by their agreement with contemporary records.

The influence of variations of the carbonic-acid contents of the atmosphere on temperature should affect the whole world simultaneously.[a] The change need not be the same in all latitudes, as is shown by Arrhenius's tables; and also by the variation in the proportion of carbonic acid with latitude, which is rendered probable by the evidence adduced by Letts and Blake.[b] Nevertheless, it might be expected that corresponding positions in the two hemispheres should be almost equally affected.

There is, however, no evidence of a glaciation in Europe[c] in Upper Carboniferous or Permian times corresponding to that of South Africa or Australia, in spite of the unusually extensive knowledge of the land conditions of that period. The Indian glaciation of Pokaran in latitude 25° N., and of Chanda in latitude 19° N., may correspond to that of South Africa from latitude 24° S. to 34° S., or of southeastern Australia from latitude 30° S. to 40° S. But the general collapse of the supposed Permian glacial conglomerates of the English Midlands, and the unconvincing evidence collected to support Carboniferous glaciation in France, as by Julien,[d] leaves us

[a] It is sure that according to the results of Muntz and Aubin there is at present a difference in the amounts of carbonic acid in the air of the Northern and Southern hemispheres; they estimate the mean amount as 0.028 per cent in the Northern and 0.027 per cent in the Southern. This difference follows from the greater area of sea in the Southern Hemisphere, which can hardly have been much greater at any previous period.

[b] E. A. Letts and R. F. Blake, "The carbonic anhydride of the atmosphere," Sci. Proc. Roy. Dublin Soc., Vol. IX, 1900, pp. 179–180.

[c] There is some evidence of glacial beds of this period on the east of the Ural Mountains.

[d] A. Julien, "Anciens glaciers de la Période Houillère dans le Plateau Central de la France," Ann. Club Alpin Français, Vol. XXI, 1894, pp. 28.

with no evidence of any refrigeration of Europe at the date of the Gondwana-Land glaciation.

Again, the Upper Paleozoic glacial deposits of southeastern Australia do not appear to have been synchronous in all the localities. The glacial deposits on the northern coast of Tasmania have been shown by Kitson[a] to be of the age of the Mersey Coal Measures of Tasmania, which may be correlated with the Lower or Greta Coal Measures of New South Wales. The Victorian glacial deposits are probably on approximately the same horizon, which agrees with some of those of New South Wales. But, according to David,[b] there were glacial deposits in New South Wales at the following different stages in the Permo-Carboniferous:

Branxton Glacial beds in the Upper Marine series.
Greta Coal Measures.
Shales with occasional erratics in the Lower Marine series.
Lochinvar Glacial Beds at the base of the Lower Marine series.

Again, whatever view may be held on the controversy as to the occurrence of warm interglacial periods during the Pleistocene glaciation of Europe, it will be generally admitted that considerable oscillations occurred in the extent of ice. Thus the evidence in the British Isles strongly supports the view that after the maximum glaciation there was a reduction in the extent of the ice, and then, after some interval, a fresh advance of valley glaciers. And such interludes, of which in the British Isles there may have been more than one, would appear to require considerable variations in the amount of carbonic acid in the atmosphere, repeated within a short period of time.

Weighty evidence is also given against Arrhenius's theory by the dates of the glaciations, as they do not correspond with those at which variations in the carbonic-acid contents of the atmosphere would be most probable. Widespread volcanic eruptions offer the simplest explanation of the addition of large volumes of carbonic acid to the atmosphere; but periods of intense volcanic activity do not appear to have been always followed by glacial epochs.

The great volcanic periods—the Devonian, the Permian, the Upper Cretaceous, the Eocene, and the Oligocene—were not followed by marked developments of glaciers. The one coincidence is in the case of the Upper Carboniferous or Permian glaciation of Gondwana Land. The Pleistocene glaciation followed a period in which volcanic action was powerful, but was probably less than at other periods not followed by glacial advance.

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[a] A. E. Kitson, "On the occurrence of glacial beds at Wynyard, near Table Cape, Tasmania," Proc. Roy. Soc. Victoria, new ser., Vol. XV, 1902, p. 34.

[b] T. W. E. David, "Discovery of glaciated boulders at base of Permo-Carboniferous system, Lochinvar, New South Wales," Journ. Roy. Soc. New South Wales, Vol. XXXIII, 1899, pp. 154–159.

Again, with the reverse case. Periods of especially active consumption of carbonic acid were not followed by glacial epochs. As Professor Chamberlin has shown, the most extensive removal of carbonic acid from the atmosphere was probably during the formation of sheets of limestone, while coal seams contain a smaller but still large amount of carbon obtained from the carbonic acid of the air. The great limestone building periods fixed enormous quantities of carbonic acid, which must have come from the atmosphere, because if obtained from the sea its fixation must have led to the transference of a fresh supply from the atmosphere. The greatest limestone periods are probably the Lower Carboniferous, the Jurassic, the Upper Cretaceous, and the Eocene and the Miocene. But none of them was a period of active glaciation. Speaking generally, they appear to have been warmer than the average. Thus in the British Isles we find unusually well-developed growths of corals in the Lower Carboniferous and the Jurassic. The British Eocene flora included plants suggestive of a warmer climate than that of the present time, while the marine faunas of the Middle Cenozoic in Europe and southern Australia indicated that those seas were then warmer than they are to-day. The Upper Cretaceous alone gives any indications of cold conditions, as shown by the probably ice-borne bowlders in the English Chalk and the temperate aspect of its fauna; but the oft-stated view that Greenland then enjoyed a subtropical climate rests on evidence which at least does not support the idea that the period was one of universal severity. The apparent independence of the times of limestone formation and glaciations is further shown by the fact that the chief glacial periods—the Cambrian in Australia and eastern Asia, the Upper Carboniferous or Permian of South Africa, India, and Australia, and the Pleistocene in the Northern Hemisphere—were not periods of great limestone formation.

CHANGES IN TEMPERATURE GRADIENT OF THE ATMOSPHERE.

The influence of changes in the composition of the atmosphere is also the basis of Dickson's theory.[a] But he traces its influence not through the variations in heat absorption by the atmosphere, but through the variations in the temperature gradient from the Tropics to the polar regions. Dickson's paper is of value from its clear statement of the facts showing that a development of glaciation is possible with only a small change in mean temperature.

Dickson appeals to a former difference in the temperature gradient between the polar and equatorial regions; he attributes the change in gradient either to the changes that are always in progress

[a] H. N. Dickson, "The mean temperature of the atmosphere and the causes of glacial periods," Geogr. Journ., Vol. XVIII, 1901, pp. 516–523.

in the obliquity of the ecliptic, or to variations in the carbonic acid in the air. He shows that either would give effects of the magnitude required; but it seems doubtful whether either will agree with the records of historical geology; for as regards the first cause, the change in the obliquity is, geologically speaking, a short and constant oscillation; and, as to the second, as it rests on the variation of carbonic acid, it is open to the same objections as to those of Arrhenius's theory.

CHANGES IN ATMOSPHERIC CIRCULATION.

That the explanation of glacial periods is to be sought in changes in the circulation of the atmosphere resulting from geographical changes has been several times suggested, in accordance with Buchan's results.[a] This principle has received its fullest application to a specific case by Harmer[b] to the Pleistocene climate of northwestern Europe. And, moreover, Dickson has shown how the distribution of the glaciations in that case corresponds with what would be expected if they were due to differences in atmospheric circulation. Such meteorological changes would be quite inadequate to explain the occurrence of a tropical climate in the arctic regions, but they would account for changes of temperature of a few degrees, and for glaciations by local concentrations of the snowfall. The difference between the climates of western Europe and eastern America is obviously due to meteorological conditions, resulting from geographical position. The differences on the two coasts of the North Atlantic were naturally first attributed to the influence of ocean currents; but with our present knowledge as to their feebleness and the bending of the Gulf Stream off Newfoundland, ocean currents may be dismissed as a very subordinate factor. A different distribution in air pressure resulting in a different circulation of the wind would probably be a more effective cause, and appears to me at present to offer the best prospects of a satisfactory solution to the problem. It is the only explanation that seems to agree with the essential facts, viz, the development of glaciation from scattered centers, and at somewhat different dates, and the apparent independence of the glaciations in distant continents, and their apparent direct dependence on a particular adjustment of meteorological conditions.

The slow march of glaciation across North America and possibly also across Europe is intelligible on this hypothesis, and there is no reason, on that theory, to expect coincidence of glaciations in the Northern and Southern hemispheres. The former glacial extensions

[a] For instance, I endeavored to show in 1894 that the more extensive glaciation of Mount Kenya was due to a local difference in the atmospheric pressure due to the former greater height of this denuded volcano. ("The glacial geology of Mount Kenya," Quart. Journ. Geol. Soc., Vol. L, 1894, pp. 527–530.)

[b] F. W. Harmer, Quart. Journ. Geol. Soc., Vol. LVII, pp. 405–472.

in Australasia can thus be easily explained; for the evidence, so far, appears to be only convincing in localities either on the edge of the antarctic regions or in local areas where the meteorological conditions are unusual. New Zealand is often quoted as having been glaciated, either in the Pleistocene or at the same time as the glaciation of Europe. But it should be remembered that there is no evidence yet of any glaciation in the North Island of New Zealand, and the former range of the glaciers in the South Island has been considerably exaggerated. On the western slope of the South Island glaciers in latitude 43° 20′ S. still come down to the level of 600 feet above the sea; and it is along that coast with its intense rainfall that the former ice extension is most clearly shown. In Tasmania the Pleistocene glaciation resulted from a heavy snowfall along the western edge of the Central Plateau, and the low moraines yet proved, occur only in the valleys leading down to the western coasts; but on the mainland of Australia the evidence of former glaciation is very scanty. Its existence has been finally established by the work of David and Pittman, on Kosciusko; but the numerous cases of Pleistocene glaciation that have been asserted in Victoria can not be maintained. I have visited all but two, and saw no evidence of glacial action in any of them; and the evidence relied on in both the places I have not seen has been described by others as explicable by non-glacial agencies.

The Permian or Carboniferous glaciations of South Africa, India, and Australia being in low latitudes and ranging down to sea level in New South Wales and in the Salt Range appears at first sight to be the most difficult problem in paleometeorology. But the question is simplified by the following considerations:

1. The geographical conditions of the areas concerned were very different from those of the present day.

2. The three best-known glacial centers occurred on the borders of the old continent of Gondwana Land, farthest from the equator, and they were probably all near mountainous country, facing seas open to the colder zones.

3. The only cases where the glacial deposits reached the sea were in the areas farthest from the Tropics, and probably most exposed to cold winds.

4. Icebergs occasionally now reach almost to the Tropics; thus in April, 1894, one was seen in the South Atlantic in latitude 26° 30′ S.

5. The glacial deposits appear to have been absent from the more tropical parts of Gondwana Land, as they disappear toward the north in both Australia and in South Africa.

Both in Australia and South Africa the glaciation occurred in areas where mountains existed near the sea. In southeastern Australia there is ample evidence that a wide Upper Paleozoic sea lay to

the east of a gulf to the northwest of Australia. In all probability there was a large extent of land stretching southward and cutting off the cold southern ocean from the seas, which extended southward from the Tropics. Under such conditions the wind systems would have traversed the Australian lands upon a different path from that which they follow now, and they would not have advanced so steadily. The winds would have carried large quantities of moisture southward, from the warm northern seas, and it would have been precipitated on the mountains of that period, which were kept cold by southerly winds, chilled by their passage over the former extension of Australia to the south. In South Africa and South America the question is simpler, as there is no proof of the glacial deposits having been laid down at sea level; they may have been formed upon the flanks of mountain areas, kept abundantly supplied with snow, by west winds blowing in from the adjacent oceans. In India the conditions were probably meteorologically similar, the glaciation having been on the cooler edge of Gondwana Land, where it was bounded by a temperate sea; and though the glaciers ranged into the Tropics in southern India as far south as latitude 17° 20′ N., there is no proof that they occurred there at low levels.

It appears, therefore, probable that variations in climate, which have been established on adequate evidence, can be accounted for by differences in atmospheric circulation, due to different distributions of land and water. All the evidence available regarding the Upper Paleozoic glaciation of Gondwana Land appears to be consistent with the view that the glaciers developed, like those of the Pleistocene glaciation of North America and of northwestern Europe, in a number of scattered localities, where mountains occurred beside the sea, and where the meteorological conditions produced a high snowfall and a low summer temperature.

URANIUM AND GEOLOGY.[a]

[With 1 plate.]

By Prof. JOHN JOLY, M. A., D. Sc., F. R. S.

INTRODUCTION.

In our day but little time elapses between the discovery and its application. Our starting point is as recent as the year 1903, when Paul Curie and Laborde showed experimentally that radium steadily maintains its temperature above its surroundings. As in the case of many other momentous discoveries, prediction and even calculation had preceded it. Rutherford and McClung, two years before the date of the experiment, had calculated the heat equivalent of the ionization effected by uranium, radium, and thorium. Even at this date (1903) there was much to go upon, and ideas as to the cosmic influence of radio-activity were not slow in spreading.[b]

I am sure that but few among those whom I am addressing have seen a thermometer rising under the influence of a few centigrams of a radium salt; but for those who pay due respect to the principles of thermodynamics, the mere fact that at any moment the gold leaves of the electroscope may be set in motion by a trace of radium, or, better still, the perpetual motion of Strutt's "radium clock," is all that is required as demonstration of the ceaseless outflow of energy attending the events proceeding within the atomic systems.

Although the term "ceaseless" is justified in comparison with our own span of existence, the radium clock will in point of fact run down and the heat outflow gradually diminish. Next year there will be less energy forthcoming to drive the clock, and less heat given off by the radium by about the one three-thousandth part of what now are evolved. As geologists, accustomed to deal with millions of years, we must conclude that these actions, so far from being ceaseless, are

[a] Address to the geological section of the British Association for the Advancement of Science, at Dublin, 1908. Reprinted by permission, with corrections by the author.

[b] See letters appearing in Nature of July 9 and September 24, 1903, from the late Mr. W. E. Wilson and Sir George Darwin referring to radium as a solar constituent, and one from the writer (October 1, 1903) on its influence as a terrestrial constituent.

ephemeral indeed, and that if importance is to be ascribed to radium as a geological agent we must seek to find if the radium now perishing off the earth is not made good by some more enduringly active substance.

That uranium is the primary source of supply can not be regarded as a matter of inference only. The recent discovery of ionium by Boltwood serves to link uranium and radium, and explains why it was that those who sought for radium as the immediate offspring of uranium found the latter apparently unproductive, the actual relation of uranium to radium being that of grandparent. But even were we without this connected knowledge, the fact of the invariable occurrence in nature of these elements, not only in association, but in a quantitative relationship, can only be explained on a genetic connection between the two. This evidence, mainly due to the work of Boltwood, when examined in detail, becomes overwhelmingly convincing.

Thus it is to uranium that we look for the continuance of the supplies of radium. In it we find an all but eternal source. The fraction of this substance which decays each year, or, rather, is transformed to a lower atomic weight, is measured in tens of thousands of millionths; so that the uranium of the earth one hundred million years ago was hardlly more than 1 per cent greater in mass than it is to-day.

As radio-active investigations became more refined and extended, it was discovered that radium was widely diffused over the earth. The emanation of it was obtained from the atmosphere, from the soil, from caves. It was extracted from well waters. Radium was found in brick-earths, and everywhere in rocks containing the least trace of demonstrable uranium, and Rutherford calculated that a quantity of radium so minute as 4.6×10^{-11} grams per gram of the earth's mass would compensate for all the heat now passing out through its surface as determined by the average temperature gradients. In 1906 the Hon. R. J. Strutt, to whom geology owes so much, not only here but in other lines of advance, was able to announce, from a systematic examination of rocks and minerals from various parts of the world, that the average quantity of radium per gram was many times in excess of what Rutherford estimated as adequate to account for terrestrial heat loss. The only inference possible was that the surface radium was not an indication of what was distributed throughout the mass of the earth, and, as you all know, Strutt suggested a world deriving its internal temperature from a radium jacket some 45 miles in thickness, the interior being free from radium.[a]

My own experimental work, begun in 1904, was laid aside till after Mr. Strutt's paper had appeared, and a valued correspondence

[a] Proc. Roy. Soc. Vol. LXXVII, p. 472, and Vol. LXXVIII, p. 150.

with its distinguished author was permitted to me. This address will be concerned with the application of my results to questions of geological dynamics.

Did time permit I would, indeed, like to dwell for a little on the practical aspect of measurements as yet so little used or understood; for the difficulties to be overcome are considerable and the precautions to be taken many. The quantities dealt with are astoundingly minute, and to extract with completeness a total of a few million millionths of a cubic millimeter of the radio-active gas—the emanation—from perhaps half a liter or more of a solution rich in dissolved substances can not be regarded as an operation exempt from possibility of error; and errors of deficiency are accordingly frequently met with.

Special difficulties, too, arise when dealing with certain classes of rocks. For in some rocks the radium is not uniformly diffused, but is concentrated in radio-active substances. We are in these cases assailed with all the troubles which beset the assayer of gold who is at a loss to determine the average yield of a rock wherein the ore is sporadically distributed. In the case of radium determinations this difficulty may be so much the more intensified as the isolated quantities involved are the more minute and yet the more potent to affect the result of any one experiment. There is here a source of discrepancy in successive experiments upon those rocks in which, from metamorphic or other actions, a segregation of the uranium has taken place. With such rocks the divergences between successive results are often considerable, and only by multiplying the number of experiments can we hope to obtain fair indications of the average radio-activity. It is noteworthy that these variations do not, so far as my observations extend, present themselves when we deal with a recent marine sediment or with certain unaltered deposits wherein there has been no readjustment of the original fine state of subdivision, and even distribution, which attended the precipitation of the uranium in the process of sedimentation.

But the difficulties attending the estimation of radium in rocks and other materials leave still a large balance of certainty—so far as the word is allowable when applied to the ever-widening views of science—upon which to base our deductions. The emanation of radium is most characteristic in behavior; knowledge of its peculiarities enables us to distinguish its presence in the electroscope, not only from the emanation of other radio-active elements but from any accidental leakage or inductive disturbance of the instrument. The method of measurement is purely comparative. The cardinal facts upon the strength of which we associate radium with geological dynamics, its development of heat, and its association with uranium are founded in the first case directly on observation and in the second on evidence so

strong as to be equally convincing. Recent work on the question of the influence of conditions of extreme pressures and temperatures on the radio-active properties of radium appear to show that, as would be anticipated, the effect is small, if indeed existent. As observed by Makower and Rutherford, the small diminution noticed under very extreme conditions in the γ radiation possibly admits of explanation on indirect effects. These observations appear to leave us a free hand as regards radio-thermal effects, unless when we pursue speculations into the remoter depths of the earth, and even there, while they remain as a reservation, they by no means forbid us to go on.

The precise quantity of heat to which radium gives rise, or, rather, which its presence entails, can not be said to be known to within a small percentage, for the thermal equivalent of the radio-active energy of uranium, actinium, and ionium, and of those members of the radium family which are slow in changing, has not been measured directly. Professor Rutherford has supplied me, however, with the calculated amount of the aggregate heat energy liberated per second by all these bodies. In the applications to which I shall presently have to refer I take his estimate of 5.6×10^{-2} calories per second as the constant of heat production attending the presence of one gram of elemental radium.

To these words of introduction I have to add the remark, perhaps obvious, that the full and ultimate analysis of the many geological questions arising out of the presence of radium in the earth's surface materials will require to be founded upon a broader basis than is afforded by even a few hundred experiments. The whole sequence of sediments has to be systematically examined; the various classes of igneous materials, more especially the successive ejecta of volcanoes, fully investigated. The conditions of entry of uranium into the oceanic deposits has to be studied, and observations on sea water and deep-sea sediments multiplied. All this work is for the future; as yet but little has been accomplished.

THE RADIUM IN THE ROCKS AND IN THE OCEAN.

The fact, first established by Strutt, that the radium distributed through the rock materials of the earth's surface greatly exceeds any permissible estimate of its internal radio-activity has not as yet received any explanation. It might indeed be truly said that the concentration of the heaviest element known to us (uranium) at the surface of the earth is just what we should not have expected. Yet a simple enough explanation may be at hand in the heat-producing capacity of that substance. If it was originally scattered through the earth-stuff, not in a uniform distribution but to some extent concentrated fortuitously in a manner depending on the origin of terrestrial ingre-

dients, then these radio-active nuclei heating and expanding beyond the capacity of surrounding materials would rise to the surface of a world in which convective actions were still possible, and, very conceivably, even after such conditions had ceased to be general; and in this way the surface materials would become richer than the interior. For instance, the extruded mass of the Deccan basalt would fill a sphere 36 miles in radius. Imagine such a sphere located originally somewhere deep beneath the surface of the earth surrounded by materials of like density. The ultimate excess of temperature, due to its uranium, attained at the central parts would amount to about 1,000° C., or such lesser temperature as convective effects within the mass would permit. This might take some thirty million years to come about, but before so great an excess of temperature was reached the force of buoyancy developed in virtue of its thermal expansion must inevitably bring the entire mass to the surface. This reasoning would, at any rate, apply to material situated at a considerable distance inward, and may possibly be connected with vulcanicity and other crustal disturbances observed at the surface.[a] The other view, that the addition of uranium to the earth was mainly an event subsequent to its formation in bulk, so that radio-active substances were added from without and, possibly, from a solar or cosmic source, has not the same à priori probability in its favor.[b]

I have in this part of my address briefly to place before you an account of my experiments on the amounts of radium distributed in surface materials. Here, indeed, direct knowledge is not attainable; but this knowledge takes us but a very few miles inward toward the center of the earth.

The igneous rocks.

The basalt of the Deccan, to which I have referred, known to cover some 200,000 square miles to a depth of from 4,000 to 6,000 feet or more, appears to be radio-active throughout. A fine series of tunnel and surface specimens sent to me by the Director of the Indian Geological Survey has enabled me to examine the radio-activity at various points. It is remarkable that the mean result does not depart much from that afforded by a long series of experiments on north of Ireland basalt and on the basalt of Greenland.

Again, the granites and syenites—and those of Mourne, Aberdeen, Leinster, Plauen, Finsteraarhorn have been examined—while variable, yet approximate to the same mean result.

In the Simplon and St. Gothard tunnels igneous rocks have been penetrated at considerable depth beneath the surface. The greatest true depth is attained, I think, in the central St. Gothard massif.

[a] See Appendix A to this article.

[b] Nature, Vol. LXXV, p. 294.

It is remarkable, and may be significant, that in these latter rocks I have reached the lowest radio-activities I have met—down to almost one-million millionth of a gram of radium per gram; although the general mean of the St. Gothard igneous rocks, owing to the high radio-activity of the Finsteraar granite at the north end of the tunnel, is not exceptionally low. Radio-active minerals seem common in the Simplon rocks, involving considerable variations in successive experiments. Some of the highest results are omitted in the mean given below, but as it is difficult to know what to allow for purely sporadic radium the mean is not very certain. In the case of a specially high result I asked Prof. Emil Werner to determine the uranium; my result was confirmed. My list of mean results on igneous rocks up to the present is the following:

Basalts (14)	[a] 5.0
Granites (6)	4.1
Syenites (1)	6.8
Lewisian gneiss (3)	5.7
Simplon (32)	7.6
St. Gothard (32)	5.1

The general mean is 6.1.

From the igneous rocks have originated the sediments after a toll of dissolved substances has been paid to the ocean. It does not of course follow necessarily that the percentage of radium, or more correctly of uranium, in the sedimentary rocks should be less than in the igneous. The residual materials might keep the original percentage of the parent rock, or even improve upon it. There are reasons for believing, however, that there would be a diminution.

Those sedimentary rocks which have been derived from material formerly in solution offer a different problem. In their case there is little or none of the original materials carried into the secondary rock, and the radio-activity will depend mainly upon how far uranium is precipitated or abstracted with the rock-making substances; in other words, upon how far the waters of the ocean will restore to the rocks what it has borrowed from them.

This brings me to consider the condition of the ocean as preparatory to quoting experiments on the sediments.

The ocean and its sediments.

The waters of the ocean, covering five-sevenths of the earth's surface to a mean depth of 3.8 kilometers, represent the most abundant

[a] This number is to be multiplied by 10^{-12}, and represents million millionths of a gram of radium per gram of material investigated. Throughout the rest of my address this understanding holds, unless where a different meaning is specified. The numbers in parentheses signify the number of different specimens investigated.

surface material open to our investigation. As the mean of a very large number of experiments upon 22 different samples of sea water from various widely separated parts of the ocean, I obtain a mean of 0.016×10^{-12} gram per cubic centimeter. There is considerable variability. Taking the mass of the ocean as 1.458×10^{18} tonnes, there must be about 20×10^{9} grams (20,000 tons) of radium in its waters.

The experiments which I have been able to make on deep-sea deposits, thanks mainly to the kind cooperation of Sir John Murray, apply to 10 different materials of typical character.

The results are so consistent as to lead me to believe that, although so few in number, they can not be far wrong in their general teaching.

The means are:

	Radium.	Extension (millions of square miles).
Globigerina ooze	7.2	49.5
Radiolarian ooze	36.7	2.5
Red clay	33.3	51.5

Diatom oozes have not yet been examined.

It is apparent from these results that the more slowly collecting sediments are those of highest radio-activity, as if the organic materials raining downward from the surface of the ocean carried everywhere to the depths uranium and radium abstracted from the waters, but in those regions where the conditions were inimical to the preservation of the associated calcareous tests there was the less dilution of the radio-active substances accumulating beneath. The next table shows that radio-activity and the percentage of calcareous matter in these deposits stand in an inverse relation:

	Calcium carbonate.	Radium.
Globigerina ooze:	*Per cent.*	
Challenger 338	92.24	6.7
Challenger 296	64.34	7.4
Red clay ooze:		
Challenger 5	12.00	15.4
Challenger 276	28.28	52.6
Radiolarian ooze:		
Challenger 272	10.19	22.8
Challenger 274	3.89	50.3

The percentages of calcium carbonate are from the report of the *Challenger* expedition. The red clay in the table, which reads as an

apparent exception, is probably a case of recent change in the character of the deposit, for the evidence of manganese nodules and sharks' teeth brought up with this clay is conclusive as to the slow rate of its collection. Readers of Sir John Murray's and Professor Renard's report will remember many cases where recent change in the character of a deposit is to be inferred.

A point of much importance in connection with our views on oceanic radio-activity is that of the presence in the waters and in the deposits of the parent radio-active substance, uranium. The evidence that the full equivalent amount of uranium is present is, I believe, conclusive.

In the first place, to so vast a reservoir as the ocean the rivers can not be supposed to supply the radium sufficiently fast to make good the decay. In a very few thousand years, in the absence of uranium, the rivers must necessarily renew almost the entire amount of radium present. I have made examination of the water of one great river only—the Nile. The quantity of radium detected was 0.0042×10^{-12} per cubic centimeter. That is less than the oceanic amount. In short, it is evident that the uranium must accumulate year by year in the oceanic reservoir, like other substances brought in by the rivers, and that the present state of the waters is the result of such actions prolonged over geological time.

While this reasoning is conclusive as regards the waters of the ocean, it does not assure us that the sediments accumulating in their depths are throughout as radio-active as their surface parts would indicate. There might be a precipitation of radium unattended by uranium, in which case their deeper parts would not be radio-active.

Against this possibility there is the evidence of such true deep-sea deposits as were formed in past times and to-day still preserve their radio-activity. For instance, the chalk, which, considering that it was undoubtedly a very rapidly formed deposit, exhibits a radio-activity quite comparable with that of the Globigerina oozes, deposits which it most nearly resembles. In this deposit, clearly, the uranium must have collected along with the calcareous materials. We can with security argue that the similar oozes collected to-day must likewise contain uranium. In the case of the red clays we have the direct determination of the uranium which Prof. Emil Werner was so good as to make at my request. Considering the difficulties attending its separation, the result must be taken as supporting the view that here, too, the radium is renewed from the uranium. Regarding the efforts of other observers to detect uranium in such deposits, it is noteworthy that without the guidance of the radium, enabling specially rich materials to be selected for analysis, the success of the investigation must have been doubtful. The material used was a red clay with the relatively large quantity of 54.4 million millionths of a

gram per gram. In a few grams of this Werner obtained up to seven-twelfths of the total theoretic amount, and of course the separation of the uranium is not likely to have been complete.

It might be thought a hopeless task to offer any estimate of the total bulk of the suboceanic deposits and from this to arrive at some idea of the quantity of radium therein contained. Nevertheless, such an estimate is not only possible, but is based on deductions which possess considerable security. As a major limit I believe the estimate of the total mass of deposit is unassailable, and such subtractive corrections as might be applied will still leave it an approximation to the truth.

The elements of the problem are simple enough; we know that the sedimentary rocks have been derived from the igneous, some 30 per cent of the latter entering into solution in the process of conversion. Some of the soluble constituents, owing to their great solubility, have remained in solution since they entered the ocean.[a] These are the salts of sodium. An estimate of the amount of these salts in the ocean gives us a clue to the total amount of rock substance which has contributed to oceanic salts and oceanic deposits since the inception of the oceans. Some years ago I deduced on this basis that the igneous rocks which are parent to the sodium in the sea must have amounted to about 91×10^{16} tons.[b]. This figure in no way involves the rate of supply by the rivers or our estimate of geological time. It only involves the quantity of sodium now in the ocean—a fairly well known factor—and the loss of this element, which occurs when average igneous rocks are degraded into sedimentary rocks—a factor also fairly well known. Mr. F. W. Clarke, to whom geological science is indebted for so much exact investigation, has recently repeated this calculation, using data deduced anew by himself, and arrives at the result that the bulk of the parent igneous rock was 84.3×10^6 cubic miles.[c] On a specific gravity of 2.6 my estimate in tons gives nearly the same result—84×10^6 cubic miles.

Now, about one-third part of this parent rock goes into solution when breaking up into a detrital sediment. The limestones upon the land are part of what was once so brought into solution. Having made deduction of these former marine deposits (and I here avail myself of Van Hise's and Clarke's estimates of the total amount of the sedimentaries and the fraction of these which are calcareous),[d] and allowing for the quantity remaining in solution in the ocean, the result leaves us with the approximation of 20,000,000 cubic miles of matter once in solution and now for the greater part existing as precipitated

[a] Trans. Royal Dublin Soc., Vol. VII, ser. 2, p. 23 et seq.

[b] Ibid., p. 46.

[c] The Data of Geochemistry, by F. W. Clarke, p. 29.

[d] Ibid., p. 31.

or abstracted deposits at the bottom of the ocean. We are to distribute this quantity over its floor. If the rate of collection had been uniform in every part of the ocean throughout geological time a depth of about one-seventh of a mile (240 meters) of deposit would cover the ocean bed.

While I believe we can place considerable reliance on this approximation, we are less sure when we attempt an estimate of its mean radio-activity. If we assume for it an average radio-activity similar to that of Globigerina ooze, we find that the quantity of radium involved must be considerably over a million tons. Apart from the value which such estimates possess as presenting us with a perspective view of the great phenomena we are dealing with, it will now be seen that it supports the finding of the experiments on sedimentary rocks and leads us to anticipate a real difference in the radio-activity of the two classes of material.

The sedimentary rocks.

The radium content of those of detrital character is indicated in the following sandstones, slates, and shales:

Shales, sandstones, grits (10)	4.4
Slates (Cambrian, Devonian)	4.7
Mud from Amazon	3.2

Some of the above are from deep borings in Carboniferous rocks (the Balfour and Burnlip bores),[a] and from their nature, where not actually of fresh-water origin, can owe little to oceanic radio-activity. Many of the following belong to the class of precipitates, and therefore owe their uranium wholly or in part to oceanic source:

Marsupites chalk	4.2
Green sandstone	4.9
Green sand (dredged)	4.5
Limestones and dolomites [Trenton, Carboniferous, Zechstein, Lias, Solenhofen (7)]	4.1
Keuper gypsum	6.9
Coral rock, Funafuti bore (4)[b]	1.7
Trias-Jura sediments, Simplon: Seventeen rocks of various characters	6.9
Mesozoic sediments, St. Gothard: Nineteen rocks of various characters	4.2

The general mean on 62 rocks is 4.7.

Making some allowance for uncertainties in dealing with the Simplon rocks, I think the experiment may be taken as pointing to the result:

[a] For these rocks, and for much other valuable material, I have to thank Mr. D. Tate, of the Scottish Geological Survey.

[b] For these I have to thank the trustees of the British Museum and Mr. A. S. Woodward, F. R. S.

Igneous rocks from 5 to 6.

Sedimentary rocks from 4 to 5.

If our estimate of oceanic radium be applied to the account of the sedimentary rocks in a manner which will be understood from what I have already endeavored to convey, there will be found to exist a fair degree of harmony between the great quantities which we have found to be in the sediments of the ocean and the impoverishment of the sediments which the experiments appear to indicate.

In all these results fresh and unweathered material has been used. The sand of the Arabian desert gave me but 0.4. Similarly low results have been found by others for soils and such materials. These are not to be included when we seek the radio-activity of the rocks.

As regards generally my experiments on the radium-content of the rocks, I can not say with confidence that there is anything to indicate a definite falling off in radio-activity in the more deeply seated materials I have dealt with. The central St. Gothard and certain parts of the Deccan have given results in favor of such a decrease. On the other hand, as will be seen later, the granite at the north end of the St. Gothard and the primitive gneiss of the Simplon show no diminution. According to the view I have put forward above as to the origin of the surface richness in radium, it is, I think, to be expected that while the richest materials would probably rise most nearly to the surface there might be considerable variability in the radio-activity of the deeper parts of the upper crust.

URANIUM AND THE INTERNAL HEAT OF THE EARTH.

While forced to deny of the earth's interior any such richness in radium as prevails near the surface, the inference that uranium exists yet in small quantities far down in the materials of the globe is highly probable. This view is supported by the presence of radium in meteoric substances and by its very probable presence in the sun—that greatest of meteorites. True, the radio-thermal theory can not be supposed to account for any great part of solar heat unless we are prepared to believe that a very large percentage of uranium can be present in the sun, and yet yield but feeble spectroscopic evidence of its existence. Taken all together, the case stands thus as regards the earth: We are assured of radium as a widely distributed surface material, and to such depths as we can penetrate. By inference from the presence of radium in meteoric substances and its very probable presence in the sun, from which the whole of terrestrial stuff probably originated, as well as by the inherent likelihood that every element at the surface is in some measure distributed throughout the entire mass, we arrive at the conclusion that radium is indeed a universal terrestrial constituent.

The dependent question then confronts us: Are we living on a world heated throughout by radio-thermal actions? This question—one of the most interesting which has originated in the discovery that internal atomic changes may prove a source of heat—can only be answered (if it can be answered) by the facts of geological science.

I will not stop to discuss the evidence for and against a highly heated interior of the earth. I assume this heated interior the obvious and natural interpretation of a large class of geological phenomena, and pass on to consider certain limitations to our knowledge which have to be recognized before we are in a position to enter on the somewhat treacherous ground of hypotheses.

In the first place, we appear debarred from assuming that the surface and central interior of the earth are in thermal connection, for it seems certain that, since the remote period when (probable) convective effects became arrested by reason of increasing viscosity, the thermal relations of the surface and interior have become dependent solely on conductivity. From this it follows if the state of matter in the interior is such as Lord Kelvin assumed—that is, that the conductivity and specific heat may be inferred from the qualities of the surface materials—we must remain in thermal isolation from the great bulk of the interior for hundreds of millions of years, and perhaps even for more than a thousand million of years. Assuming a diffusivity similar to that of surface rocks, and starting with a temperature of 7000° F., Kelvin found that after one thousand million years of cooling there would be no sensible change at a depth from the surface greater than 568 miles. In short, even if this great period—far beyond our estimates of geological time—has elapsed since the consistentior status, the cooling surface has as yet borrowed heat from only half the bulk of the earth.

It is possible, on the other hand, that the conductivity increases inward, as Professor Perry has contended; and if the central parts are more largely metallic this increase may be considerable. But we find ourselves here in the regions of the unknown.

With this limitation to our knowledge, the province of geothermal speculation is a somewhat disheartening one. Thus if with Rutherford, who first gave us a quantitative estimate of the kind, we say that such and such a quantity of radium per gram of the earth's mass would serve to account for the 2.6×10^{20} calories, which, according to the surface gradients, the earth is losing per annum, we can not be taken as advancing a theory of radio-active heating, but only a significant quantitative estimate. For, in fact, the heat emitted by radium in the interior may never have reached the surface since the convective conditions came to an end.

And here, depending upon the physical limitations to our knowledge of the earth's interior, a possibility has to be faced. That

uranium is entirely absent from the interior is, as I have said, in the highest degree unlikely. If it is present, then the central parts of the earth are rising in temperature. This view, that the central interior is rising in temperature, is difficult to dispose of, although we can adduce the evidence of certain surface phenomena to show that the rise in temperature during geological time must be small or its effects in some manner kept under control. In a word, whether we assume that the whole heat loss of the earth is now being made good by radio-active heating or not, we find, on any probable value of the conductivity, a central core almost protected from loss by the immense mass of heated material interposed between it and the surface, and within this core very probably a continuous source of heat. It is hard to set aside any of the premises of this argument.[a]

We naturally ask, Whither does the conclusion lead us? We can take comfort in a possible innocuous outcome. The uranium itself, however slowly its energy is given up, is not everlasting. The decay of the parent substance is continually reducing the amount of heat which each year may be added to the earth's central materials. And the result may be that the accumulated heat will ultimately pass out at the surface by conductivity, during remote future times, and no physical disturbance result.

The second limitation to our hypotheses arises from this transformation and gradual disappearance of the uranium. And this limitation seems as destructive of definite geothermal theories as the first. To understand its significance requires a little consideration. The fraction of uranium decaying each year is vanishingly small, about the ten thousand-millionth part; but if the temperature of the earth is maintained by uranium and consequently its decay involves the fall in temperature of the whole earth, the quantity of heat escaping at the surface attendant on the minute decrement would be enormous. An analogy may help to make this clear. Consider the familiar case of a boiler maintained at a particular temperature by a furnace within. Let the combustion diminish and the furnace temperature fall a little. The whole mass of the boiler and its contents follow the downward movement of temperature, heat of capacity escaping at the surface. An observer, only noting the outflow of radiated heat and unable to observe the minute drop of temperature, would probably ascribe to the continued action of the furnace, heat which, although derived from it in the past, should no longer be regarded as indicating the heating value of the combustion. Magnify the boiler to terrestrial dimensions; the minutest fall in temperature of the entire mass involves immense quantities of heat passing out at

[a] Prof. H. A. Wilson has made a suggestive estimate of the thermal effects of radium inclosed in the central parts of the earth. (Nature, Feb. 20, 1908.)

the surface, which no longer indicate the sustaining radio-thermal actions within.

It is easy to see the nature of the difficulties in which we thus become involved. In fact, the heat escaping from the earth is not a measure of the radium in the earth, but necessarily includes, and for a great part may possibly be referred to, the falling temperature, which the decay of the uranium involves. If we take λ (the fraction of uranium transforming each year) as approximately 10^{-10} and assume for the general mass of the earth a temperature of 1,500°, a specific heat of 0.2, and, taking 6×10^{27} as its mass in grams, we have, on multiplying these values together, a loss in calories per annum of 1.8×10^{20}. This by hypothesis escapes at the surface. But the surface loss, as based on earth gradients of temperature, is but 2.6×10^{20} calories. We are left with 0.8×10^{20} calories as a measure of the radium present. On this allowance our theories, in whatever form, must be shaped. Nor does it appear as if relief from this restriction can be obtained in any other way than by denying to the interior parts of the earth the requisite high thermal conductivity. Taking refuge in this, we are, however, at once confronted with the possibility of internal stores of radium of which we know nothing, save that they can not, probably, be very great in amount. In short, I believe it will be admitted on full examination of this question that, while we very probably are isolated thermally from a considerable part of the earth's interior, the decay of the uranium must introduce a large subtractive correction upon our estimates of the limiting amounts of radium which might be present in the earth.

But, finally, is there in all these difficulties sufficient to lead us to reject the view that the present loss of earth heat may be nearly or quite supplied by radium, and the future cooling of the earth controlled mainly by decay of the uranium? I do not think there are any good grounds for rejecting this view. Observe, it is the condition toward which every planetary body and every solar body containing stores of uranium must tend; and apparently must attain when the rate of loss of initial stores of heat, diminishing as the body grows colder, finally arrives at equilibrium with the radio-thermal supplies. This final state appears inevitable in every case unless the radio-active materials are so subordinate that they entirely perish before the original store of heat is exhausted.

Now, judging from the surface richness in radium of the earth and the present loss of terrestrial heat, it does not seem reasonable to assign a subordinate influence to radio-thermal actions; and it appears not improbable that the earth has attained, or nearly attained, this final stage of cooling.

How, then, may we suppose the existing thermal state maintained? A uniformly radio-active surface layer possessing a basal temperature

in accordance with the requirements of geology is, I believe, not realizable on any probable estimate of the allowable radium, or on any concentration of it which my own experiments on igneous rocks would justify.

But we may take refuge in a less definite statement, and assume a distribution by means of which the existing thermal state of the crust may be maintained. A specially rich surface layer we must recognize, but this need be no more than a very few miles deep; after which the balance of the radium may be supposed distributed to any depth with which we are thermally connected. Below that our knowledge is indefinite. The heat outflow at the surface is in part from the surface radium, in part due to the cooling arising from the diminishing amount of uranium, in part from the deep-seated radium. In this manner the isogeotherms are kept in their places, and a state is maintained which is in equilibrium with the thermal factors involved, but which can not be considered steady, using the word in a strictly accurate sense, in view of the decay of the uranium.

While the existing thermal state may, I think, thus be maintained by radio-active heating and radio-active decay, we find ourselves in considerable difficulties if we extend this view into the past and assume that the same could be said of any previous stage of the earth's history. If the heat emitted by the earth, when the surface was at melting temperature, was in a state of equilibrium with the radio-active supplies, then, at that date, there must have been many thousands of times the present amount of uranium on the earth, and the period of the consistentior status must be put back by thousands of millions of years. Apart from hopeless contradiction with every geological indication as to the age of the earth, difficulties in solar physics arise. For the sun must be supposed of equal duration, and we are required to assume impossible amounts of uranium to maintain its heat all that great lapse of time; and again this uranium would perish at just the same rate as that upon the earth, so that at the present time the solar mass must be, for by far the greater part, composed of inert materials of high atomic weight—the products of the transformations of the uranium family. The difficulty is best appreciated when we consider that even to maintain its present rate of heat loss by radium supplies, some 60 per cent of its mass must be composed of uranium. But there are other troubles to face if we adopt this view. The earth, or rather those parts of it which are sufficiently near the surface to lose heat at the requisite rate, would have cooled but 1 per cent in 10^8 years. Shrinkage of the outer parts and crustal thickness will be proportionately small, and we must put back our epochs of mountain building to suit so slow a rate of cooling and shrinkage and refer the earlier events of the kind into a past of inconceivable remoteness. Otherwise we must abandon the only ten-

able theory of mountain formation with which we are acquainted. On such a time scale the ocean would be supersaturated under the influence of the prolonged denudation like the waters of certain salt lakes, and the sediments would have accumulated a hundredfold in thickness.

Nor do the facts as we know them require from us such sacrifices. We are not asked to raise these difficulties on supposititious quantities of uranium for the existence of which there is no evidence. Radium has occasioned no questioning of the older view that the cooling of the earth from a consistentior status has been mainly controlled by radiation. But, on the contrary, this new revelation of science has come to smooth over what difficulties attended the reconciliation of physical and geological evidence on the Kelvin hypothesis. It shows us how the advent of the present thermal state might be delayed and geological time lengthened, so that Kelvin's forty or fifty million years might be reconciled with the hundred million years which some of us hold to be the reading of the records of denudation.

On this more pacific view of the mission of radium to geology, what has been the history of the earth? In the earlier days of the earth's cooling the radiation loss was far in excess of the radio-thermal heating. From this state by a continual convergence, the rate of radiation loss diminishing while the radio-thermal output remained comparatively constant, the existing distribution of temperature near the surface has been attained when the radio-thermal supply may nearly or quite balance the loss by radiation. The question of the possibility of final and perfect equilibrium between the two seems to involve the interior conductivity and in this way to evade analysis.

It will be asked if the facts of mountain building and earth shrinkage are rendered less reconcilable by this interference of uranium in the earth's physical history. I believe the answer will be in the negative. True, the greatest development of crustal wrinkling must have occurred in earlier times. This must be so, in some degree, on any hypothesis. The total shrinkage is, however, not the less because delayed by radio-thermal actions, and it is not hard to point to factors which will attend the more recent upraising of mountain chains tending to make them excel in magnitude those arising from the stresses in an earlier and thinner crust.

UNDERGROUND TEMPERATURE.

It would be a matter of the highest interest if we could definitely connect the rise of temperature which is observed in deep borings and tunnels with the radio-activity of the rocks. We are confronted, however, by the difficulty that our deepest borings and tunnels are

still too near the surface to enable us to pronounce with certainty on the influence of the radium met with in the rocks. This will be understood when it is remembered that a merely local increase of radio-activity must have but little effect upon the temperature unless the increase was of a very high order indeed. A clear understanding of this point shows us at once how improbable it is that volcanic temperatures can be brought within a very few miles of the surface by local radio-activity of the rocks. To account on such principles for an elevation of temperature of, say, 1,200° at a depth of three or four miles from the surface, a richness in radium must be assumed far transcending anything yet met with in considerable rock masses; and, therefore, we can hardly suppose local radio-activity of the upper crust responsible for volcanic phenomena.

When we come to apply calculation to results on the radio-activity of the materials penetrated by tunnels and borings, we at once find that we require to know the extension downward of the rocks we are dealing with before we can be sure that radium will account for the thermal phenomena observed. At any level between the surface and the base of a layer of radio-active materials—suppose the level considered is that of a tunnel—the temperature depends, so far as it is due to local radium, on the total depth of the rock mass having the observed radio-activity. This is evident. It will be found that for ordinary values of the radium content it is requisite to suppose the rocks extending downward some few kilometers in order to account for a few degrees in temperature at the level under observation. There is, of course, every probability of such a downward extension. Thus in the case of the Simplon massif the downward continuance of the gneissic rocks to some few kilometers evokes no difficulties. The same may be said of the granite of the Finsteraarhorn massif and the gneisses of the St. Gothard massif, materials both of which are penetrated by the St. Gothard Tunnel, and which appear to possess a considerable difference in radio-activity. In dealing with this subject, comparison of the results obtained at one locality with those obtained at another is the safest procedure. We must accordingly wait for an increased number of results before much can be inferred. I will now lay the cases of the two great tunnels as briefly as possible before you.

And first as to the temperature effects observed in the two cases.

The Simplon Tunnel for a length of some 7 or 8 kilometers lies at a mean distance of about 1,700 meters from the surface. At the northerly end of this stretch the rock temperature attains 55° and at the southern extremity has fallen to about 35°. The temperature of 55° is the highest encountered. The maximum predicted by Stapff, basing his estimates on his experience of the St. Gothard Tunnel, was 47°. Other authorities in every case predicted considerably lower

temperatures. Stockalper, who also had experience of the St. Gothard, predicted 36° at a depth of 2,050 meters from the surface, and Heim 38° to 39°.[a]

When the unexpectedly high temperatures were met with, various reasons were assigned. Mr. Fox has suggested volcanic heat. Others point to the arrangement of the schistosity and the dryness of the rocks, where the highest temperatures were read. The latter is evidently to be regarded more as explanation of the lower temperatures at the south end of the tunnel, where the water circulation was considerable, than of the high temperatures of the northern end. The schistosity may have some influence in bringing the isogeotherms nearer to the surface; however, not only are the rocks intensely compact in every direction, but what schistosity there is by no means inclines in the best directions for retention of heat. From the sections the schistosity appears generally to point upward at a steep angle with the tunnel axis.[b]

Where there is such variability in the temperatures, irrespective of the depth of overlying rock, there is difficulty in assigning any significant mean gradient. The highest readings are obviously those least affected by the remarkable water circulation of the Italian side. The higher temperatures afford such gradients as would be met in borings made on the level—about 31 meters per degree.

The temperatures read in the St. Gothard rocks were of a most remarkable character. For the central parts of the tunnel the gradients come out as 46.6 meters per degree. Stapff, who made these observations and conducted the geological investigations, took particular pains to ascertain the true surface temperatures of the rock above the tunnel, and from these ascertained temperatures, the temperatures in the tunnel rock and the overlying height of mountain, he calculated the gradients.

But this low gradient is by no means the mean gradient. At the north end, where the tunnel passes through the granite of the Finsteraarhorn massif, there is a rise in the temperature of the rock sufficient to steepen the gradient to 20.9 meters per degree. Stapff regarded this local rise of temperature as unaccountable, save on the view that the granite retained part of the original heat. This matter I will presently return to.

Now, it is a fact that the radium content of the Simplon rocks, after some allowance for what I have referred to as sporadic radium, stands higher than is afforded by the rocks in the central section of the St. Gothard, where the gradient is low. For the Simplon the

[a] See the account given by Schardt, Verhandl. Schweizerischen Naturf. Gesellsch. 1904, vol. 87, "Jahresversammlung," p. 204 et seq.

[b] Schardt, loc. cit.

general mean is (on my experiments) 7.1 million millionths of a gram per gram. This mean is well distributed, as follows:

Jurassic and Triassic altered sediments	6.4
Crystalline schists, partly Jurassic and Triassic, partly Archæan	7.3
Monte Leone gneiss and primitive gneiss	6.3
Schistose gneiss (a fold from beneath)	6.5
Antigorio gneiss	6.8

The divisional arrangement is Professor Schardt's. Forty-nine typical rocks are used in obtaining these results, and the experiments have been in many cases repeated on duplicate specimens. Including some very exceptional results, the means would rise to 9.1×10^{-12} grams per gram.

Of the St. Gothard rocks I have examined 51 specimens, selected to be, as far as attainable, representative.[a]

Of these, 21 are from the central region, and their mean radium content is just 3.3. The portion of the tunnel from which these rocks come is closely coincident with Stapff's thermal subdivision of regions of low temperature.[b] This portion of the mountain offers the most definite conditions for comparison with the Simplon results. The region south of this is affected by water circulation; the regions to the north are affected by the high temperature of the granite.

We see, then, that the most definite data at our disposal in comparing the conditions as regards temperature and radio-thermal actions in the two tunnels appear to show that the steeper gradient is associated with the greater radium content.

It is possible to arrive at an estimate of the downward extension of the two rock masses (assumed to maintain to the same depth their observed radio-activity), which would account for the difference in gradient. In making this estimate, we do not assume that the entire heat flow indicated by the gradients is due to radium, but that the difference in radium content is responsible for the difference of heat flow. If some of the heat is conducted from an interior source (of whatever origin), we assume that this is alike in both cases. We also assume the conductivities alike.

Calculating on this basis, the depth required to establish on the radium measurements the observed difference in gradients of the Central St. Gothard and of the Simplon, we find the depth to be about 7 kilometers on the low mean of the Simplon rocks and 5 kilometers on the high mean. There is, as I have already said, nothing improbable in such a downward extension of primitive rocks having the radio-

[a] I would like to express here my acknowledgments to the trustees of the British Museum for granting me permission to use chips of the rocks in their possession, and especially to Mr. Prior for his valuable assistance in selecting the specimens.

[b] Trans. North of England Min. and Mech. Eng., Vol. XXXIII, p. 25.

activities observed; but as a different distribution of radium may, of course, obtain below our point of observation, the result can only claim to be suggestive.

Turning specially to the St. Gothard, we find that a temperature problem of much interest arises from the facts recorded. The north end of the tunnel for a distance of 2 kilometers traverses the granite of the Finsteraarhorn massif. It then enters the infolded syncline of the Usernmulde and traverses altered sediments of Trias-Jura age for a distance of about 2 kilometers. After this it enters the crushed and metamorphosed rocks of the St. Gothard massif, and remains in these rocks for 7½ kilometers. The last section is run through the Tessinmulde for 3 kilometers. These rocks are highly altered Mesozoic sediments.

I have already quoted Stapff's observations as to the variations of gradient in the northern, central, and southern parts of the tunnel. He writes: "They (the isotherms) show irregularities on the south side, which clearly depends on cold springs; they bend down rapidly, and then run smoothly inclined beneath the water-filled section of the mountain. Other local irregularities can be explained by the decomposition of the rock; but there is no obvious explanation of the rapid increase in the granite rocks at the northern end of the tunnel (2,000 meters), and it is probably to be attributed to the influence of different thermal qualities of the rock on the coefficient of increase. For the rest these 2,000 meters of granite belong to the massif of the Finsteraarhorn, and, geologically speaking, they do not share in the composition of the St. Gothard. Perhaps these two massifs belong to different geological periods (as supposed for geological reasons long ago). What wonder, then, if one of them be cooler than the other." (Loc. cit., p. 30.)

Commenting on the explanation here offered by Stapff, Prestwich[a] states his preference for the view that the excess of temperature in the granite is due to mechanical actions to which the granite was exposed during the upheaval of this region of the Alps.

The accompanying diagram shows the distribution of temperature as given by Stapff, and the distribution of radium as found from typical specimens of the rocks. There is a correspondence between the two which is obvious, and when it is remembered that the increase in radio-activity shown at the south end would have been, according to Stapff, masked by water circulation, the correspondence becomes the more striking. The small radium values in the central parts of the tunnel are remarkable. The rocks of the Central St. Gothard massif are apparently exceptionally poor in radium.

At the north end the excess of radium is almost confined to the granite, the rock to which Stapff ascribed the exceptional tempera-

[a] Proc. Roy. Soc., Vol. XLI, p. 44.

tures. The radium of the Usernmulde is probably not very important, seeing that these sediments can not extend far downward. The principal local source of heat appears located more especially beneath the synclinal fold, for Stapff's table (loc. cit., p. 31) of the gradients beneath the plain of Andermatt shows a rising gradient to a point about 2,500 meters from the north entrance of the tunnel. It is observable that the radio-activity of the granite increases as it approaches the Usernmulde and attains its maximum (14.1) where it dips beneath the syncline.

The means of radium content in the several geological sections into which the course of the tunnel is divisible are as follows:

Granite of Finsteraarhorn	7.7
Usernmulde	4.9
St. Gothard massif	3.9
Tessinmulde	3.4

The central section, however, if considered without reference to geological demarcations, would, as already observed, come out as barely 3.3. And this is the value of the radio-activity most nearly applicable to Stapff's thermal subdivision of the region of low temperature.

If we accept the higher readings obtained in the granite as indicative of the radio-active state of this rock beneath the Usernmulde, a satisfactory explanation of the difference of heat flow from the central and northern parts of the tunnel is obtained. Using the difference of gradient as basis of calculation, as before, we find that a downward extension of about 6,000 meters would, if the outflow took place in an approximately vertical direction, account for the facts observed by Stapff. This depth is in agreement with the result as to the downward extension of the St. Gothard rocks as derived from the comparison with the Simplon rocks.

We are by no means in a position to found dogmatic conclusions on such results; they can only be regarded as encouragement to pursue the matter further. The coincidence must be remarkable, however, which thus similarly localizes radium and temperature in roughly proportional amounts, and permits us, without undue assumptions, to explain such remarkable differences of gradient. There is much work to be done in this direction, for well-known cases exist where exceptional gradients in deep borings have been encountered—exceptional both as regards excess and deficiency.

RADIO-ACTIVE DEPOSITS AND THE INSTABILITY OF THE CRUST.

At the meeting of the British association held last year at Leicester I read a note on the thermal effects which might be expected to arise at the base of a sedimentary accumulation of great thickness due to the contained radium.

The history of mountain building has repeated itself many times; ages of sedimentation, with attendant sinking of the crust in the area of deposition, then upheaval, folding up of the great beds of sediment, and even their overthrusting for many miles. So that the mountain ranges of the world are not constituted from materials rising from below, save in so far as these may form a sustaining core, but of the slowly accumulating deposits of the ages preceding the upheaval.

The thickness of collected sediments involved in these great events is enormous, and although uncertainty often attends the estimation of the aggregate depths of sedimentation, yet when we consider that unconformities between the deposits of succeeding eras represent the removal of vast masses of sediment to fresh areas of deposition, and often in such a way as to lead to an underestimate of the thickness of deposit, the observations of the geologist may well indicate the minor and not the major limit. Witness the mighty layers of the Huronian, Animikean, and Keweenawan ages, where deposits measured in miles of thickness are succeeded by unrecorded intervals of time, in which we know with certainty that the tireless forces of denudation labored to undo their former work. Each era represents a slow and measured pulse in the earth's crust, as if the overloading and sinking of the surface materials induced the very conditions required for their reelevation. Such events, even in times when the crust was thinner and more readily disturbed than it is now, must have taken vast periods of time. The unconformity may represent as long a period as that of accumulation. In these Proterozoic areas of America, as elsewhere on the globe and throughout the whole of geological history, there has been a succession in time of foldings of the crust always so located as to uplift the areas of sedimentation, these upheavals being sundered by long intervals, during which the site of sedimentation was transferred and preparation made for another era of disturbance. However long deferred, there seems to be only the one and inevitable ending, inducing a rhythmic and monotonous repetition surely indicative of some cause of instability attending the events of deposition.

The facts have been impressively stated by Dana:

> A mountain range of the common type, like that to which the Appalachians belong, is made out of the sedimentary formations of a long-preceding era; beds that were laid down conformably and in succession until they had reached the needed thickness; beds spreading over a region tens of thousands of square miles in area. The region over which sedimentary formations were in progress in order to make, finally, the Appalachian Range reached from New York to Alabama and had a breadth of 100 to 200 miles, and the pile of horizontal beds along the middle was 40,000 feet in depth. The pile for the Wahsatch Mountains was 60,000 feet thick, according to King. The beds for the Appalachians were not laid down in a deep ocean, but in shallow waters, where a gradual subsidence was in progress; and they at last, when ready for the genesis, lay

in a trough 40,000 feet deep, filling the trough to the brim. It thus appears that epochs of mountain making have occurred only after long intervals of quiet in the history of a continent.

The generally observed fact that the deposition of sediments in some manner involves their ultimate upheaval has at various times led to explanations being offered. I think I am safe in saying that although the primary factor, the compressive stress in a crust which has ceased to fit the shrinking world within it, has probably been correctly inferred, no satisfactory explanation of the connection between sedimentation and upheaval has been advanced. The mere shifting upward of the isogeotherms into the deposits, advanced as a source of local loss of rigidity by Babbage and Herschel, need not involve any such loss so long as the original distance of the isogeotherms from the surface is preserved.

We see in every case that only after great thicknesses of sediments have accumulated is the upheaval brought about. This is a feature which must enter as an essential condition into whatever explanations we propose to offer.

Following up the idea that the sought-for instability is referable to radio-thermal actions, we will now endeavor to form some approximate estimate of the rise of temperature which will be brought about at the base of such great sedimentary accumulations as have gone toward mountain building, due to the radium distributed throughout the materials.

The temperature at the base of a feebly radio-active layer, such as an accumulation of sediments, is defined in part by radio-active energy, in part by its position relative to the normal isogeotherms, whether these latter are in turn due to or influenced by radio-thermal supplies or not. It is convenient and, I think, allowable to consider these two effects separately and deal with them as if they were independent, the resultant state being obtained by their summation.

In dealing with the rise of temperature at the base of a radio-active layer we arrive at an expression which involves the square of the depth. This is a very important feature in the investigation, and leads to the result that for a given amount of radium diffuse distribution through a great depth of deposit gives rise to a higher basal temperature than a more concentrated distribution in a shallower layer.

But this will not give us the whole effect of such a deposit. Another and an important factor has to be taken into account. We have seen that the immediate surface rocks are of such richness in radium as to preclude the idea that a similar richness can extend many miles inward.

Now, it is upon this surface layer that the sediments are piled, and as they grow in thickness this original layer is depressed deeper and deeper, yielding under the load, until at length it is buried to the full

depth of the overlying deposit. This slow and measured process is attended by remarkable thermal effects. The law of the increase of temperature with the square of the depth comes in, and we have to consider the temperature effect not merely at the base of the deposited layer, but that due to the depression and covering over of the radium-rich materials upon which the sediments were laid down.

The table which follows embodies an approximate statement of the thermal results of various depths of deposit supposed to collect under conditions of crustal temperature such as prevail in this present epoch of geological history:

Thickness of sedimentary deposit.	Resulting rise of isogeotherms.	Weakening of earth's crust as defined by the rise of the geotherm at 40 kilometers
Kilometers.	*Kilometers.*	*Kilometers.*
6	7.4	40 to 32.6
8	10.2	40 to 29.8
10	13.3	40 to 26.7
12	16.7	40 to 23.3
14	20.4	40 to 19.6

I have deferred to the conclusion of this address an account of the steps followed in obtaining the above results. It is clearly impossible within the limited time allotted to me to make these quite clear. It must suffice here merely to explain the significance of the figures.

The first column gives the depth of sedimentary deposit supposed to be laid down on the normal radio-active upper crust of a certain assumed thickness and radio-activity. From the rise of temperature which occurs at the base of this crust (due to the radio-activity, not only of the crust, but of the sediments) the results of the second column are deduced, the gradient or slope of temperature prevailing beneath being derived from the existing surface gradients corrected for the effects of the radio-thermal layer. The third column is intended to exhibit the effect of this shift of the geotherms in reducing the strength of the crust. I assume that at a temperature of 800° the deep-seated materials lose rigidity under long-continued stress. The estimated depth of this geotherm is, on the assumptions, about 40 kilometers. The upward shift of this geotherm shows the loss of strength. Thus in the case of a sedimentary accumulation of 10 kilometers the geotherm defining the base of the rigid crust shifts upward by 13 kilometers, so that there is a loss of effective section to the amount of 30 per cent.[a]

[a] See Appendix B to this article.

As regards the claims which such figures have upon our consideration, my assumptions as to thickness and radio-activity of the specially rich surface layer are doubtless capable of considerable amendment. It will be found, however, that the assumed factors may be supposed to vary considerably, and yet the final results prove such as, I believe, can not be ignored. Indeed those who are in the way of making such calculations, and who enter into the question, will find that my assumptions are not specially favorable, but are, in fact, made on quite independent grounds. Again, a certain class of effects has been entirely left out of account, effects which will go toward enhancing, and in some cases greatly enhancing, the radio-thermal activity. I refer to the thickening of the crust arising from tangential pressure, and, at a later stage, the piling up and overthrusting of mountain-building materials. In such cases the temperature of the deeper parts of the thickened mass must still further rise under the influence of the contained radium. These effects only take place, indeed, after yielding has commenced, but they add to the element of instability which the presence of the accumulated radio-active deposits occasions, and doubtless increase thermal metamorphic actions in the deeper sediments and result in the refusion of rocks in the upper part of the crust.[a]

The effect of accumulated sediment is thus necessarily a reduction in the thickness of that part of the upper crust which is capable of resisting a compressive stress. Over the area of sedimentation, and more especially along the deepest line of synclinal depression, the crust of the globe for a period assumes the properties belonging to an earlier age, yielding up some of the rigidity which was the slow inheritance of secular cooling. Along this area of weakness—from its mode of formation generally much elongated in form—the stressed crust for many hundreds, perhaps thousands, of miles finds relief, and flexure takes place in the only possible direction—that is, on the whole upward. In this way the prolonged anticline bearing upward on its crest the whole mass of deposits is formed, and so are borne the mountain ranges in all their diversity of form and structure.

We have in these effects an intervention of radium in the dynamics of the earth's crust, which must have influenced the entire history of our globe, and which, I believe, affords a key to the instability of the crust; for after the events of mountain building are accomplished, stability is not attained, but in presence of the forces of denudation the whole sequence of events has to commence over again. Every

[a] Prof. C. Schmidt (Basel) has recently given reasons for the view that the Mesozoic schists of the Simplon at the period of their folding were probably from 15,000 to 20,000 meters beneath the surface (*Ec. Geol. Helvetiæ*, Vol. IX, No. 4, p. 590). As another instance consider the compression of the Laramide range (Dawson, *Bull. Geol. Soc. Amer.*, Vol. XII, p. 87).

fresh accession of snow to the firn, every passing cloud contributing its small addition to the torrent, assists to spread out once more on the floor of the ocean the heat-producing substance. With this rhythmic succession of events appear bound up those positive or negative movements of the strand which cover and uncover the continents, and have swayed the entire course of evolution of terrestrial life.

Oceanic deposits.

The displacements of the crust which we have been considering are now known to be by no means confined to the oceanic margins. The evidence seems conclusive that long-continued movements have been in progress over certain areas of the sea floor, attended with the formation of those numerous volcanic cones upon which the coral island finds foundation. Here there are plainly revealed signs of instability and yielding of the crust (although, perhaps, of minor intensity) such as are associated with the greater movements which terminate in mountain building. I think it will be found, when the facts are considered, that we have here phenomena continuous with those already dealt with, and although the conditional element of a sufficient sedimentary accumulation must remain speculative, the evidence we possess is in favor of its existence.

One of the most interesting outstanding problems of deep-sea physiography is that of the rates of accumulation of the several sorts of deposit. In the case of the more rapidly collecting sediments there seems to be no serious reason why the matter should not be dealt with observationally. I hope it may be accomplished in our time. For my present purpose I should like to know what may or may not be assumed in discussing the accumulation of radio-active sediments on the ocean floor.

As regards the rate of collection of the noncalcareous deposits, the nearest approach to an estimate is, I think, to be obtained from the exposed oceanic deposits of Barbados. In the well-known paper of Jukes Brown and Harrison [a] on the geology of that island, it is shown that the siliceous radiolarian earths and red clays aggregate to a thickness of about 300 feet. These materials are true oceanic deposits, devoid of terrigenous substances. They collected very probably during Pliocene and, perhaps, part of Pleistocene times. Now there is evidence to lead us to date the beginning of the Pliocene as anything from one million to three million years ago. The mean of these estimates gives a rate of collection of 5 millimeters in a century. This sounds a very slow rate of growth, but it is too fast to be assumed for such deposits generally. More recent observations might, indeed, lead us to lengthen the period assigned to the deposition of these

[a] Quart. Journ. Geol. Soc., Vol. XLVIII, p. 210.

oceanic beds; for if, following Professor Spencer,[a] we ascribe their deposition to Eocene times, a less definite time interval is indicated; but the rate could hardly have been less than 3 millimeters in a century. The site of the deposit was probably favorable to rapid growth.

We have already found a maximum limit to the average thickness of true oceanic sediments, and such as would obtain over the ocean floor if the rate of collection was everywhere the same and had so continued during the past. If there is one thing certain, however, it is that the rates of accumulation vary enormously. The 1,200 or 1,500 feet of chalk in the British Cretaceous, collected in one relatively brief period of submergence, would alone establish this. Huxley inferred that the chalk collected at the rate of 1 inch in a year. Sollas showed that the rate was probably 1 inch in forty years. Sir John Murray has advanced evidence that in parts of the Atlantic the cables become covered with Globigerina ooze at the rate of about 10 inches in a century. Finally, then, we must take it that the fair allowance of one-seventh of a mile may be withheld in some areas and many times exceeded in others.

Now, it is remarkable that all the conditions for rapid deposition seem to prevail over those volcanic areas of the Pacific from which ascend to the surface the coral islands—abundant pelagic life and comparatively shallow depths. Indeed, I may remind you that the very favorable nature of the conditions enter into the well-known theory of coral-island formation put forward by Murray.

The islands arise from depths of between 1,000 and 2,000 fathoms. These areas are covered with Globigerina ooze having a radio-activity of about 7 or 8. The deeper-lying deposits around—red clay and radiolarian ooze—show radio-activities up to and over 50. From these no volcanic islands spring.

These facts, however, so far from being opposed to the view that the radio-activity and crustal disturbance are connected, are in its favor. For while those rich areas testify to the supply of radio-active materials, the slow rate of growth prevailing deprives those deposits of that characteristic depth which, if I may put it so, is of more consequence than a high radio-activity. For the rise in temperature at the base of a deposit, as already pointed out, is proportional to the square of the thickness. In reality the dilution of the supplies of uranium which reach the calcareous oozes flooring the disturbed areas is a necessary condition for any effective radio-thermal actions.

It might appear futile to consider the matter any closer where so little is known. But in order to give an idea of the quantities in-

[a] Quart. Journ. Geol. Soc., Vol. LVIII, p. 354 et seq.

volved I may state that, if my calculations are correct, a rate of deposition comparable with that of the chalk prevailing for ten million years would, on assumptions similar to those already explained when discussing the subject of mountain building, occasion a rise of the deeper isogeotherms by from 20 to 30 per cent of their probable normal depth.

In making these deductions as to the influence of radium in sedimentary deposits I have so far left out of consideration the question of the time which must elapse in order that the final temperature-rise in the sediments must be attained. The question we have to answer is: Will the rate of rise of temperature due to radium keep pace with the rate of deposition, or must a certain period elapse after the sedimentation is completed to any particular depth before the basal temperature proper to the depth is attained?

The answer appears to be, on an approximate method of solution, that for rates of deposition such as we believe to prevail in terrigenous deposits—even so great as 1 foot in a century, and up to depths of accumulation of 10 kilometers and even more—the heating waits on the sedimentation. Or, in other words, there is thermal equilibrium at every stage of growth of the deposit; and the basal temperature due to radio-active heating may at any instant be computed by the conductivity equation. For accumulations of still greater magnitude the final and maximum temperature appears to lag somewhat behind the rate of deposition.

From this we may infer that the great events of geological history have primarily waited upon the rates of denudation and sedimentation. The sites of the terrigenous deposits and the marginal oceanic precipitates have many times been convulsed during geological time because the rates of accumulation thereon have been rapid. The comparative tranquillity of the ocean floor far removed from the land may be referred to the absence of the inciting cause of disturbance. If, however, favorable conditions prevail for such a period that the local accumulations attain the sufficient depth, here, too, the stability must break down and the permanency be interrupted.

Upheaval of the ocean floor, owing to the laws of deep-sea sedimentation, should be attended with effects accelerative of deposition—a fact which may not be without influence. But although ultimately sharing the instability of the continental margins, the cycle of change is tuned to a slower periodicity. From the operation of these causes, possibly, have come and gone those continents, which many believe to have once replaced the wastes of the oceans, and which with all their wealth of life and scenic beauty have disappeared so completely that they scarce have left a wreck behind. But those forgotten worlds may be again restored. The rolled-up crust of the earth is still rich in energy borrowed from earlier times, and the slow but

mighty influences of denudation and deposition are forever at work. And so, perchance, in some remote age the vanished Gondwána Land, the lost Atlantis, may once again arise, the seeds of resurrection even now being sown upon their graves from the endless harvests of pelagic life.

Appendix A.

Convective movement of uranium to the earth's surface (p. 359).

The estimate of temperature given assumes (1) that the mass of igneous material is spherical, and (2) that its surface is kept at constant temperature, heat escaping freely. The first assumption is in favor of increasing the estimate of temperature, and probably would not generally be true, especially of a mass moving upward. The second assumption tends to give a lower estimate of temperature, and is certainly inaccurate, as the surrounding materials are nonconducting and must favor the accumulation of radio-active heat.

On assumptions (1) and (2) and on Barus's results for the thermal expansion of diabase between 1,100° and 1,500°,[a] and results of my own on basalt,[b] which are in approximate agreement, and assuming the mean excess of temperature to be 500° and the surrounding material to be at a fluid temperature, the force of buoyancy comes out at over 60 dynes per cubic centimeter of the spherical mass. This is an underestimate.

If we may assume that the Deccan Trap is indeed an instance of such an overheated mass escaping at the surface, and that similar radio-active masses rising up from beneath at various times in the past may have affected the crust, we have at our disposal a local source of energy of plutonic origin which may account for much.

Appendix B.

Sedimentation and rise of geotherms (p. 378).

The depth of the upper radio-active layer is, of course, unknown. We possess, however, the means of arriving at some idea of what it must be. The quantitative thermal conditions impose a major limit to its average thickness, and the indications of injected rocks suggest a minor limit.

If 2.6×10^{20} calories is the heat output of the whole earth per annum, and if we assign only one-fifth of this amount to cooling due to decay of the uranium, then, on the assumption that the earth is no longer losing any part of its original store of heat, we have about 2×10^{20} representing radium heating. From this the allowance of terrestrial radium per square centimeter inward is 2.3×10^{-5} grams. This would give a major limit. But it is probable that a large part of this radium is located in more deeply seated parts of the earth. If we take 10^{-5} as contained in the normal radio-active surface layer, and assume (what according to my experiments should not be far from the truth) that the average radio-activity is 3, we arrive at a thickness of 12 kilometers.

Some such mean value is necessitated by the evidence we derive from the radio-activity of igneous rocks. These rocks must in many cases be derived

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[a] Phil. Mag., Vol. XXXV, p. 173.

[b] Trans. Roy. Dublin Soc., Vol. VI, p. 298.

from considerable depths. Such outflows as the Deccan may indicate local subcrustal conditions; so also may the eruptions of certain volcanic areas. But those extrusions which have attended mountain building, more especially its closing phases, appear to indicate general conditions, and involve the existence of such radio-active materials at considerable depths. If we assume a thickness for the radio-active part of the crust much less than the 12 kilometers, difficulties are met with on this line of reasoning.[a]

Proceeding now to the derivation of the results given in the table, p. 16. The equation $k\theta = qhx(D - \frac{x}{2})$ (where θ is the temperature at the depth x, D being the total depth of the radio-active layer, q the radium per cu. cm. in grams, h the heat output of one gram of radium per second, k the thermal conductivity) is easily derived by considering the conditions of thermal flow in the layer, supposed to lose heat only at the surface.[b]

The aggregate depths of radio-active material in the several cases of sedimentary deposit assumed in my address amount to 18, 20, 22, 24, and 26 kilometers. I assume the mean radio-activity to be 3.5, and the average conductivity to be 4×10^{-3}. From this the basal temperatures are found, as due to radio-thermal actions. These temperatures are to be augmented by the temperatures proper to the several depths, which depend upon the conducted interior heat. To estimate these we require to apportion the observed average surface gradient (taken as 32 meters per degree) between radio-active effects in the upper layer and the flow of heat from within. The radio-thermal gradient comes out at about 75 meters; the inner gradient is accordingly 56 meters. Hence the total temperature at the base of each radio-active mass is obtained. But the geotherms proper to the several depths, 18, 20, etc., kilometers, under conditions prevailing elsewhere in the crust, are easily found from the value of θ for the normal layer (82° C.), and adding the temperature due to interior heat. From the difference of the temperatures we finally find the rise of the geotherms.

As conveyed in my address, I have found on several different values of the thickness and radio-active properties of the surface layer, results in every case showing large values for the rise of the geotherms. The data assumed above are by no means the most favorable.

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[a] See p. 379, ante, and footnote as bearing on the possible displacement of the geotherms.

[b] See Strutt, Proc. Roy. Soc., Vol. LXXVII, p. 482.

AN OUTLINE REVIEW OF THE GEOLOGY OF PERU.

[With 5 plates.]

By George I. Adams.

Introduction.

More than a century has elapsed since Humboldt beheld the grand Cordilleras in northern Peru, and more than three-quarters of a century has passed since d'Orbigny studied the section of the Andes in the southern part of the country. Since then many scientists have been attracted to the region and have contributed to the knowledge of its geology. Their writings are scattered in numerous publications in English, German, French, and Spanish, and no summary of this information has been made. The writer in attempting to learn what is known concerning the subject has gleaned the material which constitutes this paper. The arrangement and presentation of it in the form of an outline review has been undertaken with the hope that it may serve as an introduction to the broader problems with which later geologists may have to deal.

The author's contributions to the geology of Peru have been published in bulletins of the Corps of Engineers of Mines of Peru, and relate principally to the distribution of the Tertiary formations of the coast of which he made a reconnaissance. Later, while engaged in private work, he traveled in the Titicacan region of Peru and Bolivia, crossed the Cordilleras, and entered the forest region of southern Peru, and also saw something of the Cordilleras of the central part of the country. It is not his intention, however, to attempt to incorporate his observations during these journeys to any great extent in this paper, but rather to use them as an aid to the interpretation of the work of others.

The geologic relations of the rocks of Peru have thus far been explained by written descriptions accompanied in some cases by sections, but there are practically no geologic maps. It is to be hoped that the mapping of some type localities may soon be undertaken and that the columnar sections for the various regions may be established and the paleontologic studies correlated with them. The time has arrived when simple geologic reconnaissance can not be expected to yield satisfactory results.

Accompanying this paper will be found a bibliography of the more important literature, and in the footnotes some additional references are given. Nearly all of the literature of the subject has been consulted in the preparation of this review, but it has not been deemed advisable to publish a more complete bibliography, since some of the articles with elaborate titles have in reality little value and, being quite inaccessible to the general student, can hardly hope to hold a place with the more important contributions, which embody the essential truths with fewer errors.

Physical and Climatic Regions.

THE THREE REGIONS OF PERU.

The dominant physical feature of Peru is the lofty range of the Andes which lies near the Pacific Ocean and forms a barrier between the narrow strip of desert coast and the extensive wooded plains of the Amazon. Accordingly, the country is commonly recognized as presenting three naturally defined regions which differ in their physical features and climate; namely, the coast, the sierra, and the forest, or "montaña," as it is called in Peru. The use of these terms originated with the inhabitants, and they have to a considerable extent found their way into scientific literature. The name "montaña" is apt to be misleading, especially to a foreigner, since it suggests mountains. "Selva," meaning forest, would seem to be more appropriate. If terms are selected which may be broadly used in considering the South American continent one may appropriately speak of the Pacific coastal region, the Andes Mountain region, and the Amazon plains region. These terms have physiographic signification and should come into use in scientific writings. The extension of these regions may be learned from the accompanying map (pl. 1).

PACIFIC COASTAL REGION.

Definition.

The distinction between the coast and the sierra as commonly made is one of climate and is indicated by differences in agriculture. In the coast the agricultural products are those of the tropical and subtropical climates, while those of the sierra are such as are found in the temperate zones. The transition from one region to the other is abrupt because of the steep declivity of the Pacific slope of the Andes.

With the exception of the part of Peru adjacent to the Gulf of Guayaquil, the division between the coast and the sierra corresponds with the approximate western limit of general annual rainfall on

the Pacific slope of the Andes. This is largely determined by elevation and temperature, and is indicated as one travels from town to town by the character of the roofs of the houses of the natives. The writer in drawing the line upon his published maps[a] used this as a basis for his observations and inquiries in order to obtain reliable information.

Near the Gulf of Guayaquil, where the zone of rainfall is deflected to the westward from the slope of the Andes over the coastal plains and to the Pacific Ocean, the division between coast and sierra would be made by continuing the trend of the line into Ecuador, taking into consideration the character of the agriculture, which varies with the temperature dependent on elevation. For Peru the distinction based on climate holds fairly well, but in Ecuador it is less satisfactory, since under the Equator and in a region of rainfall the zones of vegetation and agriculture do not correspond with the topographic distinction also implied.

Divisions of the coastal region.

The coastal region of Peru may be divided into plains areas and mountainous areas. The plains, according to their geographic positions in the country, may be called the "northern," "south central," and "southern." Between the northern and south central plains, and likewise between the south central and southern, the coast is mountainous. The northern and south central plains extend inland from the shore of the Pacific, but the southern plains are separated from the sea by a coast range of hills. The mountainous divisions of the coast are diversified by the stream valleys and their tributary dry valleys and present a very broken topography. The southern one of these two mountainous areas, considered as a mass, rises abruptly from the sea and presents many aspects of a dissected plateau. The northern area is characterized by a more broken coast line and the mountains rise in a ragged, irregular way toward the sierra. It would seem to be an open question as to whether these mountainous areas should be classed with the coast or the Andes region. Along the inner border of the plains are the "foothills" rising to the sierra, and at a corresponding distance inland in the mountainous divisions of the coast there is a transition zone known as the "valley heads of the coast" (cabezeras de los valles), where the valley floors become narrow and stony, so that the agriculture of the coast is impossible, and the mountains rise on either side into the temperature and climate of the sierra.

[a] Maps reproduced in this report as Plates Nos. 2, 3, 4, and 5.

THE ANDES MOUNTAIN REGION.

The distinction between the coast and the sierra has already been explained. [The division line between the sierra and the Amazon region would seem to be simple enough if it is based on the presence of the forest, as is implied when the word "montaña" is used. (See p. 386 above.)] The tree line, however, especially in the northern part of Peru, according to the data which the writer has obtained from reading, rises well up onto the flanks of the Andes, and indeed covers some of the mountains which may be appropriately classed with the Andes region. It may also be noted that the limits of the forest have never been accurately shown on any map. It would seem

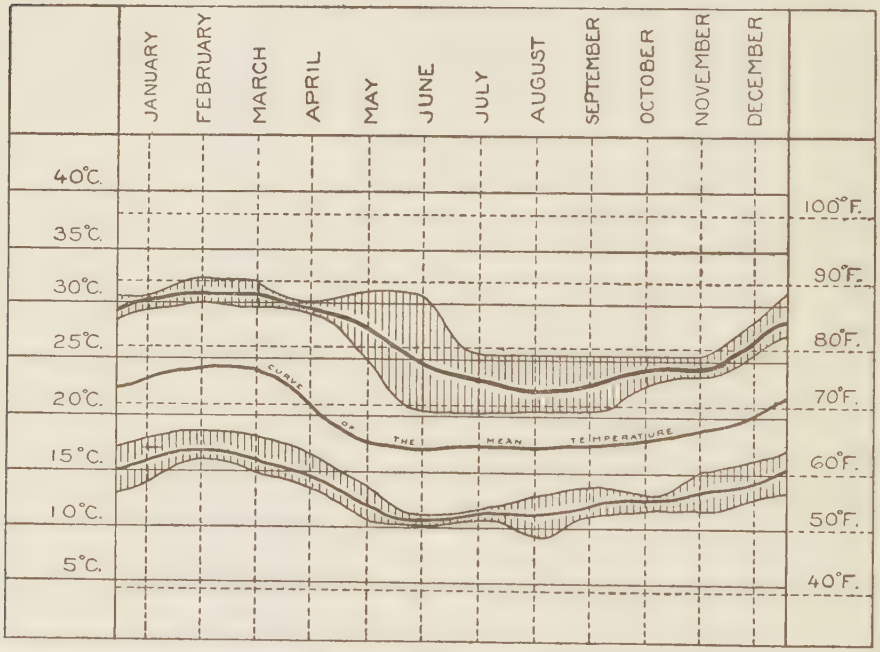

FIG. 1.—Variations of temperature at Lima.

proper to restrict the Amazon region to the plains lying to the east of the mountains in order to make the division a physiographic one. It is not possible to draw this line from information now available. In the accompanying sketch map of the Cordillera of the Andes the hachuring of the mountainous area has been done as accurately as possible from available data, but it will be remembered that Raimondi's map of Peru, which is the most detailed, is known to be defective, and to a considerable extent the hachuring on it is imaginary.

Divisions of the Andes region.

The main features of the Andes are the Cordilleras proper, which will be described in some detail later. Corresponding with them

are the great inter-Andean valleys, which are occupied by streams tributary to the Amazon and which are shown in a general way on the hachured map, and which may be named from the rivers occupying them. On the Pacific slope there is one inter-Andean valley between the Cordillera Negra and Blanca known as the "Valley of Huaylas" (Callejon de Huaylas). In addition should be noted the Titicaca Lake basin. If one attempts to go further into the classification of the physiographic features, there are many short ranges of mountains or spurs from the main Cordillera, some of which are named on Raimondi's map, and also high plains and table-lands (frequently called "punas") which are worthy of distinction.

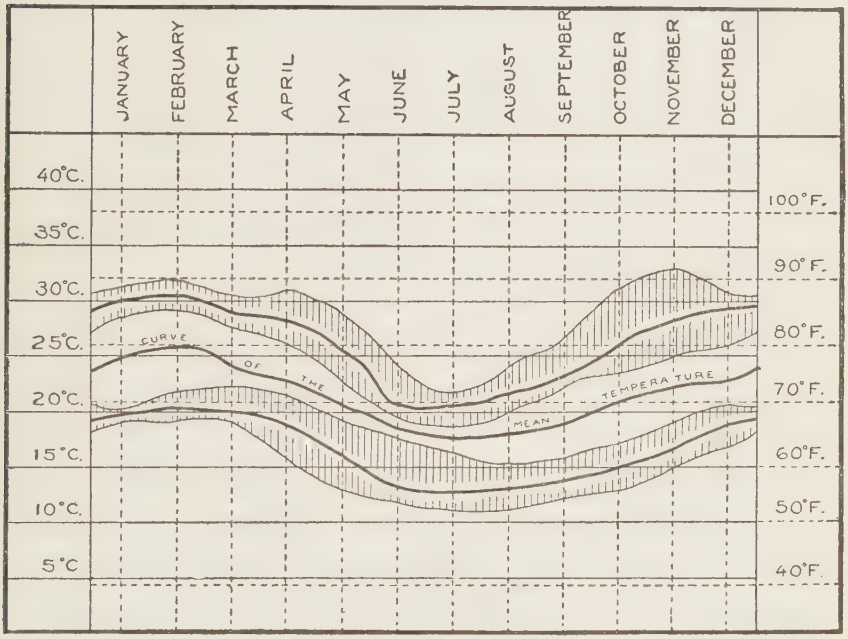

Fig. 2.—Variations of temperature at Ica.

Rainfall in the Andes.

The rain which falls in the Andes region is brought as vapor from the Atlantic and most of it is precipitated in the Amazon region or on the eastern flank of the first Cordillera which it encounters. During the summer season the clouds rise higher and pass farther to the west, distributing their moisture on the Cordilleras and a part of it crosses the Continental Divide or the western Cordillera. It is generally believed that the rainfall on the Pacific slope, the limit of which has already been discussed, comes over the Cordilleras, except in the region of the Gulf of Guayaquil. This is in accordance with the observations of many travelers and the general theory of the

influence of the trade winds. Clouds are not seen passing to the Cordillera from the Pacific. The mists of the coast which drift inland from the Pacific form at the season when the sky in the Cordillera is clear and their movements are with the land and sea breezes. Systematic observations of the rainfall in the Andes region have been carried on at only one locality, namely, Cailloma, which is situated north of Arequipa and just to the east of the Continental Divide. From the published data the writer has constructed the accompanying diagrams (figs. 3 and 4) which show the annual and monthly variations of the rainfall.

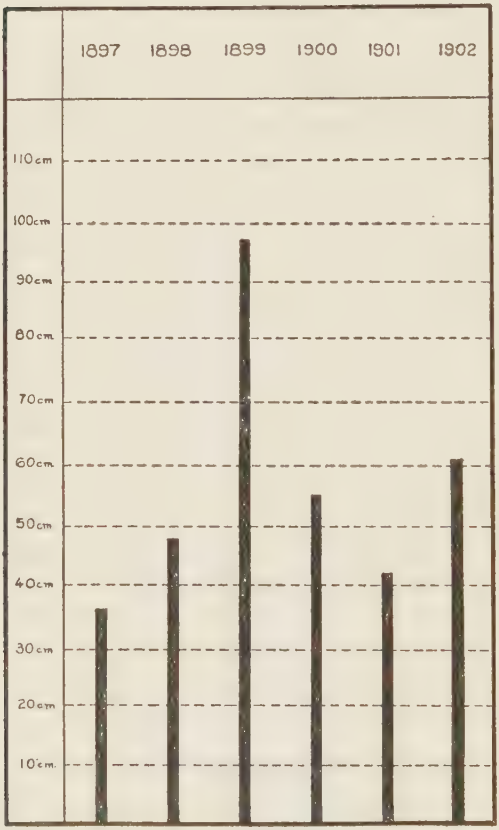

FIG. 3.—Annual variation of rainfall at Cailloma during seven years.

The Cordilleras of the Andes.

DESCRIPTION BY HUMBOLDT, 1802.

Although Humboldt did not have Peru as an object of special study and did not visit the country excepting to see the coast at Pisco and Lima and to travel in the northern highlands between Cajamarca and the Maranon,[a] he nevertheless gave a graphic and to a large extent a correct description of the chain of the Andes, availing himself of data furnished by others. He says, in substance, that in southern Peru there are two branches of the Andes which include between them the Titicaca basin. To the north of the Titicaca basin there is a knot which includes Vilcanota, Carabaya, Abancay, Huando, and Parinacochas. After this knot of Cuzco and Parinacochas, in latitude 14° S., the Andes present a second bifurcation, and northward the two chains lie on the east and west of the river Jauja.

[a] Raimondi, El Peru, Volume I, page 15.

The eastern chain extends on the east of Huanta, the convent of Ocopa and Tarma, the western chain passes Castrovereyna, Huancavelica, Huarochari, and Yauli, inclosing a lofty table-land. In latitude 10° 11′ the two branches unite in the knot of Huanuco and Pasco (Cerro de Pasco). From this point northward the Andes divide into three chains. The eastern lies between the Huallaga and Pachitea (Ucayali) rivers, the second or central between the Huallaga and the Maranon, while the third lies between the Maranon and the coast. The eastern range lowers to a range of hills, and is lost in latitude 6° 15′ on the west of Lamas. The central, after forming the rapids and cataracts of the Amazon, turns to the northwest and joins the knot of Loja in Ecuador. From the most certain information which he obtained he concluded that to the east of the chain which passes to the east of Lake Titicaca and northward to Huanuco a wide mountainous land is situated, which is not a widening of the eastern chain itself, but rather that it consists of heights which surround the foot of the Andes like a penumbra, filling in the whole space between the Beni and the Pachitea (Ucayali).

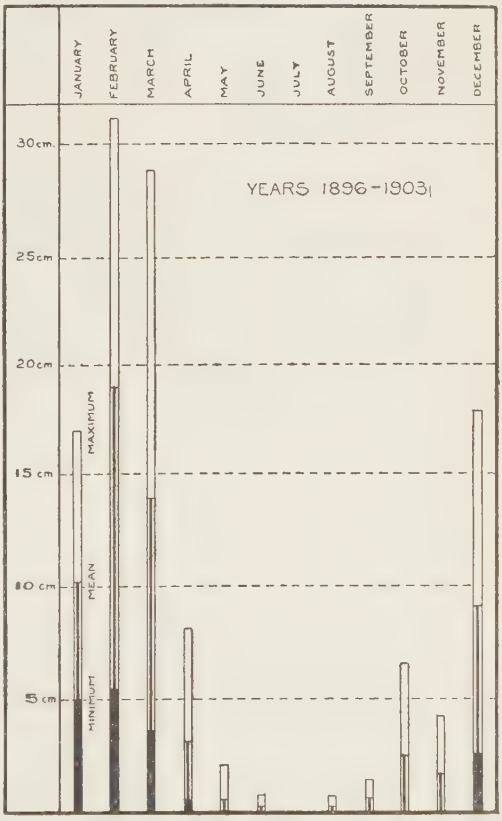

FIG. 4.—Monthly variation of rainfall at Cailloma during seven years.

Humboldt also made interesting comments on the direction of the Andes. He noted that in Chile and Upper Peru (Bolivia), from the Straits of Magellan to the parallel of Arica (18° 28′ 35″ S.), the whole mass of the Andes runs from south to north in the direction of a meridian at the most 5° NE., but from the parallel of Arica the coast and the two Cordilleras east and west of the alpine lake of Titicaca abruptly change their direction and incline to the northwest.

In this region, as in general in every considerable widenings of the Cordillera, the grouped summits do not follow the principal axes in uniform and parallel directions, and he remarked that the general disposition of the Andes in this latitude is well worth the attention of geologists. From where the Cordilleras unite in the knot of Cuzco (Vilcanota) their direction is N. 80° W. He calls attention to the fact that the direction of the coast follows these changes, and remarks that the parallelism between the coast and the Cordilleras of the Andes is a phenomenon the more worthy of attention as it occurs in several parts of the globe where the mountains do not in the same manner form the shore.

Description by Raimondi.

It is to be regretted that Raimondi did not publish a description of the Andes. However, his writings contain much information, and in his edited notes published in the chapter "Apuntes Orograficos," in Volume IV of El Peru there is a partial description of the Cordilleras. He adopted the nomenclature of Humboldt. The Andes is used as a general term for the whole mountain system, and the various branches are spoken of as "Cordilleras." The branch to the east of Lake Titicaca he called the "Cordillera Oriental" and the one to the west the "Cordillera Occidental." The union of these branches to the north of Lake Titicaca he calls the "Knot of Vilcanota," taking the name from a snow-capped peak. From this knot northward he recognized three branches instead of the two somewhat vaguely described by Humboldt. The Cordillera Occidental follows the direction of the coast. The Cordillera Central separates the valleys of the Apurimac and the Vilcanota or Urubamba rivers, while the Cordillera Oriental separates the inter-Andean region from the forest region of the interior. These three Cordilleras unite in the Knot of Cerro de Pasco, from which point northward three branches diverge. The Cordillera Occidental for a portion of its way is divided into two, the western of which is known as the "Cordillera Negra" (Black Cordillera) and the eastern or main one takes in that region the name "Cordillera Blanca" (White Cordillera) because of its snow-covered peaks. The Cordillera Central separates the Maranon and Huallaga rivers, while the Cordillera Oriental separates the Huallaga from the Pachitea and Ucayali. The Cordillera Central describes a curve, and is cut by the Maranon at the falls of Manseriche. The Cordillera Oriental lowers, and is cut by the Huallaga at the Falls of Aguirre and then runs in a northwest direction and joins the Cordillera Central. Humboldt states that it dies out in latitude 6° 15′. With this exception, it will be seen that in the northern part of Peru the description by Raimondi does

not differ materially from that by Humboldt. Raimondi gives a description of the Cordillera Occidental and notes a list of 42 of its passes, which vary from 2,186 meters to 5,075 meters. From Huamachuco in latitude 7° 45′ southward the 27 passes are more than 4,000 meters above the sea. The lowest pass is that of Huarmaca, in the department of Piura, which is 2,180 meters.

His further description of this Cordillera as to structure, age, and snow line, etc., will be given under other heads in this paper. Here, however, it will be noted that he says the southern part of the Cordillera Occidental is not a single range, but rather a broad elevated band or high plateau, on which are situated volcanic peaks. It may perhaps be added here with propriety that the Continental Divide is a continuous range and that the volcanic peaks do not follow the Cordillera, but are found in an irregular double line crossing the western part of the high plateau. The relation of this line of peaks to the change in direction of the Cordillera is not unlike that of a string to a bow.

It will be remembered that Humboldt spoke of a mountainous area to the east in the forest region. Raimondi did not touch on this point, and indeed it is not yet possible to tell just what is the disposition of the mountains of this region, for although many explorations have been made the wooded country has prevented the mapping of the topographic features. The Cordillera Central, according to Humboldt, joins the Occidental in the knot of Loja, in Ecuador. Perhaps Raimondi did not ttouch on this point in his description because Loja is outside of Peru, and consequently beyond the limit of his explorations. He seems to have accepted the statements of Humboldt in his mapping.

Wolf, however (1892), in his description of the Andes, says that he does not agree with the opinion that the Cordillera Oriental unites in the knot of Loja, as is shown on the map of Ecuador by Santiago y Morona and of Peru by Raimondi. He states that the Cordillera cut by the Pongo de Manseriche (Falls of Manseriche) is the last branch of the Peruvian mountains which reaches the Amazon. It appears not to be very high, since explorers speak of 600 meters at the locality of the falls, and he thinks that to the north it lowers and is lost in the plains between the rivers Santiago and Morona.

Wolf also says that to the east of Ecuador from where the rivers are navigable the country is a great plain, with only small areas of gradual undulations, and that the high mountains of the old maps, as also those of Raimondi, are imaginary and do not exist.

The accompanying sketch map (pl. 1) shows the disposition of the Cordilleras according to the foregoing description. The Ecuadoran portion is from the sketch published by Wolf.

THE AMAZON PLAINS REGION.

It is to be regretted that so little systematized information is available concerning the Amazon region. It has been explored principally along its great waterways, and the forest has prevented travelers from obtaining comprehensive views of its physical features, which are of relatively minor relief. There are some grassy plains. These are of insignificant extent as compared with the tree-covered area. Most of the sheets of Raimondi's map in the Amazon region are without hachures, and Wolf has called attention to the fact that the mountains shown to the east of Ecuador and in a region which Raimondi did not visit are wholly fanciful. A chain of hills or an escarpment gives rise to the falls of the Madierra River, but further than this there is little found in the writings of explorers excepting the mention of bluffs along the streams and occasionally hilly areas. Accordingly, the region must be for the present dismissed without further attempt to describe or outline its physical features.

Sedimentary Formations.

CAMBRIAN.

The Cambrian has not been identified in Peru by means of fossils. In some instances in the literature the Cambrian has evidently not been considered as a separate era, but has been included in the Silurian according to former usage. Accordingly formations have been discussed in connection with the Silurian which may be of Cambrian age. Steinmann (1904) has described green slates near Chanchamayo, which he says are surely pre-Silurian, but the absence of fossils does not permit of their age being proved. He mentions[a] having lost his collections of fossils from Bolivia which would have thrown light on the Cambrian and Silurian formations.

SILURIAN.

In his section from southern Peru into Bolivia d'Orbigny (1848) described the Silurian as represented in the Cordillera Oriental, where it has associated with it granite, which he stated forms the axis of the mountain range and constitutes some of the highest peaks.

Forbes (1861) outlined the area of the Silurian as extending from north of Cuzco in Peru along the Cordillera Oriental into Bolivia and southward to beyond Potosi. He found it to present physical features similar to the Silurian of Europe. He says that it consists

[a] Introduction to paper by A. Ulrich on "Palæozoische Versteinerungen aus Bolivien."

of clay slates, shales, and quartzites, but he found no limestones. The fossils which he collected were examined by Salter and showed that probably the whole Silurian is represented. Forbes called attention to the fact that the formation contains quartz veins, and that these have given rise to auriferous gravels. He contradicted the statement of d'Orbigny that the peak Illimani in Bolivia is a granite peak as shown in the section, and says that Illimani and Illampu (Sorata) are composed of slates.

Raimondi (1867) described the Cordillera Occidental as containing slates cut by quartz veins carrying gold, and later (1873) in outlining the geology of the Department of Ancachs he classes the slates as Silurian.

In southern Peru Balta (1897) has classed the slates in the Province of Carabaya and Sandia as Silurian because of the presence of graptolites, and this classification was followed by Pflucker[a] who, however, contributed little to our knowledge of the Silurian.

Ochoa, in his bulletin[b] on the Province of Huanuco, in the central part of the Peruvian Andes, makes a brief reference to the finding of graptolites near Huacar, from which fact he concluded that the Silurian is present there.

Steinmann (1904) identified by means of graptolites the lower Silurian in the region of Tarma, also in the central region of the Peruvian Andes, and he states that the granite associated with the Silurian in the Cordillera Oriental made its appearance in lower Silurian time.

Farther to the north Raimondi (1873), in describing the geology of the Department of Ancachs, states that in the Province of Huari, near Uco, in the valley of the Maranon, there are older sediments with a great formation of talcose slates with quartz veins, which he refers to the Silurian, although he did not mention any fossils. He also states that there is a similar area on the western slope of the Cordillera Nevada (Occidental) at Pallasca. Farther to the north and in the foothills of the Cordillera Occidental, in passing over the divide from Motupe to Olmos and in the vicinity of Olmos, the writer saw extensive exposures of slates cut by numerous quartz veins and stringers which have been prospected for gold. Mention is here made of the area because of its resemblance to the Silurian, but it should not be definitely classed until fossils have been found.

A paper which has an important bearing on the paleontology of the Silurian was published by A. Ulrich (1892) describing an ex-

[a] Informe sobre los yacimentos auriferous de Sandia, Bol. del Cuerpo de Ingenieros de Minas del Peru No. 26, 1905, Luis Pflucker.

[b] Recursos minerales de la provincia de Huanuco, Bol. del Cuerpo de Ingenieros de Minas del Peru No. 9, 1904, Nicanor G. Ochoa.

tensive collection of fossils from the Silurian and Devonian of Bolivia made by Steinmann. Inasmuch as the same faunas probably extend into Peru the descriptions of the fossils will be of value when similar studies are undertaken farther northward. Recently Dereims (1906) has described the occurrence of the Silurian at many places in Bolivia, some of which are near the border of Peru in the Titicaca basin, although most of them are to the south in the Cordillera Real (Oriental) of Bolivia, but he has not yet described his collections of fossils.

DEVONIAN.

The first recognition of a Devonian locality which has a bearing on the geology of Peru was by d'Orbigny (1842), who made collections in the Titicaca Lake region in Bolivia and found fossils which he described as characteristic of that period.

Forbes (1861) when in the field did not distinguish the Devonian, but included it with the upper Silurian. Later he was induced by Salter, who studied the collections of fossils, to show the Devonian in his section because of the finding of *Phacops latifrons*, which is admitted to be a truly Devonian species. Forbes's localities are in Bolivia, near Lake Titicaca.

Mention has already been made of the collections from Bolivia made by Steinmann which were studied by A. Ulrich (1892) and found to contain an interesting series of Silurian and Devonian fossils. The descriptions by Ulrich will be of value when the Devonian in adjacent parts of Peru receives critical study.

Still later Dereims (1906) has described the occurrence of the Devonian in Bolivia, near Lake Titicaca. He says it consists of sandstones of different colors and thicknesses, alternating with shales of less importance. He obtained a collection of fossils, some of which he mentions, but he has not yet published his paleontologic studies.

All the foregoing literature pertains to Bolivia, but it has a direct bearing on the geology of Peru, since the Devonian undoubtedly extends across the border in the Titicaca basin. Thus far no Devonian fossils have been described from Peru, but Dueñas[a] (1907) obtained fossils from Taraco northwest of Lake Titicaca which Bravo has reported to be Devonian, although he did not determine them specifically.

CARBONIFEROUS.

The Carboniferous in Bolivia was studied by d'Orbigny (1848), who described a number of fossils. This was the first information which gave a definite reason to suppose that the Carboniferous exists

[a] Enrique I. Dueñas. Bol. del Cuerpo de Ingenieros de Minas del Peru No. 53, p. 156. See footnote.

in Peru, since the localities are very near the border. D'Orbigny also referred the rocks at Arica to the Carboniferous on very slight evidence, but this has been refuted by Forbes. The writer[a] found fossils at Arica, which, according to Bravo, are Cretaceous, although he did not determine them specifically.

The Carboniferous areas examined by Forbes (1861) are on the peninsula of Copacabana and the projecting headland opposite on Lake Titicaca. On account of a declaration of war Forbes was placed in a suspicious position, since these localities are on the frontier between Peru and Bolivia. He, however, obtained a collection of fossils which were determined by Salter. Forbes states that the Carboniferous is also to be found to the north of Lake Titicaca.

The fossils collected by Agassiz (1876), together with some others, were studied by Derby (1876), who described 9 Carboniferous species from Yampata and the island of Titicaca. He also found a Spirifer in materials brought by James Orton from the Pichis River, and in his notes says that he has recognized Productus and Streptorhynchus from near Mayobamba in northern Peru. Agassiz, in the notes accompanying Derby's paper, states that specimens of Fusulina were sent to Mr. Brady for identification. The notes as to the occurrence of the Carboniferous are by Agassiz, who says that near Lake Titicaca it lies in a rather limited elongated basin, with the axis in a northwest-southeast direction. He identified the Carboniferous at Vilca, Santa Lucia, and Sumbay, and says that Mr. Orrego stated that Carboniferous is found as far north as Caylloma, and quotes Orton as saying that Raimondi reported he had traced the Carboniferous series to a height of 1,400 feet on the Apurimac at a locality intermediate between the Pichis River and Cuzco. It would seem to the writer that until fossils are found the identification of the Carboniferous at the places mentioned by Agassiz, and especially those reported by Mr. Orrego, should not be definitely referred to the Carboniferous. The writer in journeying to Caylloma observed sedimentary formations which appear to be Cretaceous.

Balta (1899) reviewed the Carboniferous of Peru and published a sketch map showing two areas in which the Carboniferous had been shown to exist, namely, in the Titicaca basin and the locality from which Orton's Carboniferous fossils were obtained. He added nothing especially new.

A small Carboniferous area was reported[b] by Fuchs (1900) as being found in the peninsula of Paracas, just south of Pisco, on the Pacific coast. The formation there contains some thin coal which

[a] See Boletin del Cuerpo de Ingenieros de Minas del Peru, No. 45, p. 19, 1906.

[b] Nota sobre el Terreno Carbonifero de la peninsula de Paracas, F. C. Fuchs, Bol. de Minas, T. XVI, 1900.

an attempt is being made to exploit. With the coal, fossil plants were found by Fuchs. This is an important addition to our knowledge of the distribution of the Carboniferous because of the geographic position of the area.

Steinmann (1904) reported the finding of a few characteristic Carboniferous fossils southeast of Tarnia.

The Carboniferous in Bolivia, especially in the region of Lake Titicaca, was studied by Dereims (1906), who describes the formation as composed of sandstones and shales, with a bed of dark limestone at the base and with coal beds. He investigated the coal four leagues north of Mocomoco, at Ococoya and Calacala, where it does not exceed 80 centimeters and consists largely of shale impregnated with carbonaceous matter and is not workable. In the peninsula of Copocabaña, near Yamupata, he saw thin beds of coal, which have formerly been worked, but the coal is mixed with shale and contains so much sulphur that it can not be used. He states that on the island of Titicaca it is of the same general character. His conclusion in regard to the Carboniferous in Bolivia is that it is the lower or Dimantian stage, and is everywhere marine and contains no workable or good coal.

PERMIAN.

The Permian is not known to be present in Peruvian territory. Certain sandstones in Bolivia which extend into southern Peru in the Titicaca region were early classed as Permian or Triassic by Forbes because of their resemblance to the typical Permian of Russia described by Murchison. Forbes, however, states that no fossils having been found, the age of the beds is a question for inquiry. The formation contains salt and gypsum beds and native copper, the celebrated mines of Cora-Cora being found in them.

Steinmann (1906) has discussed the Cora-Cora copper deposits and has given the name Puca sandstone to the formation in which they are found. He says that the formation comprises the youngest marine sediments in Bolivia and has a thickness of more than 1,000 meters. By the finding of fossils near Potosi, in southern Bolivia,[a] in related formations a higher age than Jura is indicated, and accordingly he assigns them to the Cretaceous.

Dereims (1906) says that at Santa Lucia, near Potosi, he found reddish sandstones and reddish gypsiferous shales with some beds that are calcareous, which are of Permian age. The calcareous bed is full of *Chemnitzia potosensis*, first described by d'Orbigny. He remarks that d'Orbigny has referred this formation to the Trias on lithologic grounds, but from the fossils it appears that it is Permian-

[a] Compare Steinmann, Hoek, and V. Bistraus. Zentralblatt für Mineralogie etc., 1904, p. 3, zur Geologie des sudostichen Boliviens.

Carboniferous or Permian. It will be remembered that d'Orbigny described *Chemnitzia potosensis* from the Triassic, but the diagnostic value of the genus for indicating the Carboniferous or Permian may well be questioned, since the genus is also found in the Mesozoic. Moreover, it will be recalled that the evidence by Steinmann just cited is opposed to the conclusions of Dereims.

TRIASSIC.

D'Orbigny (1842) referred to the Triassic a series of variegated reddish sandstones in Bolivia. He found a number of fossils but mentions only one, *Chemnitzia potosensis*, the others having been lost. The age of these beds seems to still be in doubt, Dereims having referred them (1906) to the permo-Carboniferous as has already been mentioned.

Later Forbes (1861) commented on the classification by d'Orbigny and states that it would appear that d'Orbigny proceeded on the supposition that no link in the geologic chain should be deficient. Forbes classed these rocks as Permian or Jurassic, but stated that their age is a question requiring more study.

Raimondi (1873) in his volume on the Department of Ancachs classed as Triassic certain red sandstones and shales with salt and gypsum. This seems to have been done in accordance with the general relations of the rocks and to make the geologic succession complete. It will be remembered that the fossils sent by Raimondi to Gabb were not given close diagnostic values, and so the classification by Raimondi has really little value. In several places Raimondi speaks of the Triassic as being present, but unfortunately little reliance can be placed on this. According to Steinmann's later writings (1904) the red sandstones and shales with salt and gypsum beds are to be classed as Cretaceous (Lower Liassic).[a]

JURASSIC.

D'Orbigny (1842) found no fossils of Jurassic age and did not color any part of his section as Jurassic. He discussed the probabilities of its being present in South America.

Crosnier (1852), in his explorations on the east slope of the Cordillera Occidental, found some fossils which were determined by M. Bayle as Jurassic. He mentions an Arca like *Arca gabnelis* of the Neocomian. Also an Ammonite from near Oroya was likewise determined as Jurassic.

Forbes (1860) classed as Jurassic or Permian a series consisting principally of sandstones aggregating more than 6,000 feet. These

[a] Bol. No. 12, p. 24.

rocks were classed by d'Orbigny as Devonian and Carboniferous and in part Triassic, but he cited no fossils. Forbes says that the beds contain plant remains (coniferous indeterminable) and he was informed that a complete Saurian head had been extracted from the beds by M. Ramon Due, but was not successful in obtaining it nor some fossil bones and teeth now in the Museum of Avignon in France, sent there by M. Granier of La Paz. The character of these beds, as already stated in describing the Permian, is like the typical Permian of Russia. Forbes concluded that their age must await the finding of fossils.

Raimondi (1873), in his study of the Department of Ancachs, classes as Jurassic certain formations containing coal and yielding ammonite fossils. However, he had no other determination for his fossils than that furnished by Gabb, which was not very critical and so we must rely on later work for the differentiation of the Jurassic. It will be seen later that the plants and invertebrates from the coal horizon of the Cordillera Occidental have been shown to be Cretaceous. However, Raimondi in some instances was probably correct in assigning formations to the Jurassic, since it is now known to be present and has yielded numerous fossils. Bravo has called attention to the fact that Gottsche[a] has made mention of an ammonite from Morococha which is in the Freiburg collections.

Fossil ammonites from Huallanca, in the Department of Ancachs, collected by Durfeldt and belonging to the Freiburg Museum, were studied by Steinmann (1881) and considered by him as indicating the Tithon (which is homotaxial with the Portlandian) and belonging in the upper part of the Jurassic.

CRETACEOUS.

The island of San Lorenzo at Callao was examined by Dana, and his description is published in the report of the Wilkes expedition (1849). He made some detailed sections of the rocks and found some fossils which he considered as indicating the oolitic. He refers in a footnote to the fact that James Delafield had reported[b] upon some fossils which Doctor Brinkerhoff had collected from the island and presented to the New York Lyceum of Natural History. Delafield did not venture an opinion as to the age of the fossils.

Doctor Pickering, who was with Dana, found an ammonite at the head of the Chancay Valley at an elevation of 15,000 feet in rocks similar to those of San Lorenzo Island. This specimen is described in the appendix of the report as *Ammonites pickeringi*. Some fossils from Trujillo are also figured.

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[a] Uber Jurassiche versteinerungen aus der Argentinische Cordillere. Dr. Carl Gottsche, Cassel, 1878.

[b] Amer. Journ. Sci., Vol. 38, p. 201, 1839.

D'Orbigny discussed the occurrence of the Cretaceous in South America, and in his section shows an extension of porphyritic rocks on the west slope of the Cordillera Occidental; he did not differentiate the Cretaceous, but evidently included them with the porphyries with which they are interbedded.

In the section which Forbes made from Arica to Bolivia he classified (1861) as oolitic (Liassic) the rocks at Arica, which he describes as shales, claystones, and embedded porphyries, and stated as his reason for doing so that to the south of the district which he studied the rocks are abundantly fossiliferous and had yielded to the researches of Bayle and Coquand and Phillipi about 35 species of recognized oolitic forms. On his map he showed a considerable extent of oolitic in the Cordillera Occidental of southern Peru.

Apparently, Raimondi attempted to identify the fossils which he collected, although he did not describe them. He evidently used the fossils as a guide in determining as best he could the age of the sedimentary formation, which he discusses in his various writings. When he sent his collections to Gabb to be described he accompanied them by a letter (1867) in which he outlined the geographical distribution of the sedimentary formations of Peru. According to his idea, Cretaceous (with Jurassic, Lias, and Trias) is distributed principally in the western Cordillera. He thought the stratified rocks near the Port of Ancon, at San Lorenzo, near Callao, and at Chorillos, to be Jurassic or Liassic. These localities have since proven to be Cretaceous, as will soon appear in this paper. Unfortunately, Gabb's determination of the Mesozoic fossils was delayed and, moreover, he did not give to them such diagnostic value as would help Raimondi to revise his ideas in his later writings.

In his volume on the Department of Ancachs he classed (1873) as Cretaceous certain limestones with echinoderms, oysters, and other fossils. This seems to be correct as viewed in connection with the determination of the Cretaceous in other localities, where it consists largely of limestone and contains similar fossils.

In his geological sketches (1876) Agassiz states that Mr. William Chandless, upon his return from the River Purus, presented him with fossil remains of the highest interest and undoubtedly belonging to the Cretaceous. They were collected on the River Aquiry, latitude 10°–11° south, longitude 67°–69° west, in localities varying from 430 to 650 feet above sea level. Among the material, remains of a Morosaurus and of fishes were found. Chandless[a] says that the material identified by Agassiz consisted of two perfectly preserved vertebræ of Morosaurus. These are the only vertebrate remains thus

[a] "Notes on the River Aquiry, the principal affluent of the Purus." William Chandless, Journal Royal Geogr. Soc., Vol. 36, p. 119.

far mentioned as from the Cretaceous of Peru. It may not be improper to recall, in this connection, that Forbes in discussing the Permian or Triassic of Bolivia says that he was informed that a complete Saurian head had been extracted from the beds and also some fossil bones and teeth. This material appears never to have been studied critically and not even a generic name has been applied.

The Mesozoic fossils sent to Gabb by Raimondi were described (1877) and figured, but since then they have not been reviewed critically and studied in connection with further collections, excepting that the descriptions have been referred to by later workers. The opinions which Gabb ventured to give were not very definite, as would naturally be the case in dealing with meager and scattered collections. In several instances he simply stated the age of the beds according to the opinion of Raimondi. Gabb gave with his paper a synopsis of the South American invertebrate paleontology and a bibliography of South American paleontology.

A number of fossils collected by Durfeldt from the coal-bearing formation at Pariatambo, Peru, and belonging to the Freiburg Museum, were studied by Steinmann (1881) and determined as indicating the Albien and marine origin of the beds.

This was the first paper by Steinmann dealing critically with the paleontology of Peru. To him and his colaborers we are indebted for a number of subsequent papers which are published under his supervision as Contributions to the Geology and Paleontology of South America.

The material from Peru studied by Gerhardt (1897) consisted of a block containing fossils from Morococha (Pariatambo), sent by Don Jose Barranca, of Lima, to Doctor Steinmann. By dissolving the stone in acid a small fauna was obtained. The additional fossils from the Strasburg Museum were those collected by Reiss and Stubel from the same place. With this material he was better able to determine the age of the beds which Gabb had considered as Liassic and Steinmann had determined as Albien on the border between upper and lower Cretaceous. He concludes that the coal-bearing beds of Pariatambo are of marine origin, and that certainly in Albien time in Peru a fauna reigned which was related to that of Europe and north Africa. In studying the fossils of Venezuela he identified *Ammonites Andii* Gabb from Peru with a Venezuela Lenticras, and so concluded that the lower Senon was present in Peru.

The paleontological paper on the Cretaceous of South America, by Paulcke (1903), in so far as it pertains to Peru, is a filling out of the fauna studied by Gerhardt and extends our knowledge of the upper Cretaceous. Most of the specimens were collected by Reiss and Stubel in Cajamarca and nearby places in northern Peru, but some were collected by J. Bamberger. He found the Senonian of the

upper Cretaceous represented. He says, in summing up concerning the lower Cretaceous, that in Peru the only highest part of the lower Cretaceous (the Albien) is certainly known and the Neocomian probably may be present.

In various bulletins[a] of the Corps of Engineers of Mines of Peru J. J. Bravo has published (1904–1906) determinations of Cretaceous fossils and has described some species. This is the most important work done in paleontology by a Peruvian. Through his efforts the corps is gradually acquiring a collection of fossils and developing a paleontologic literature. Bravo has called attention to the fact that previously Pflucker y Rico had collected fossils and given a relation[b] of localities and a list of fossils obtained in the districts of Yauli (Morococha), but the collections were lost. He also cites two species of Pseudo-ceratites from Yauli, described by Hyatt.[c]

In 1904 Habich, in his report on the coal deposits of Checras, in the Province of Chancay,[d] mentions the finding of Cretaceous fossils in limestones and plants in the coal-bearing beds.

Similarly Malaga Santolalla (1904) found fossils in Hualgayoc[e] and concluded that the middle or upper part of the Cretaceous is represented there. He also gives[f] a list of fossils from the Province of Cajamarca described by various authors.

In his report on the Province of Colendin[g] he likewise gives a list of Cretaceous fossils. Lisson (1905) collected a few fossils from near Chorullos, just south of Lima, and described[h] some Annelid tubes, and a new species *Sonneratia Pfluckeri* and redescribes *S. Raimondianus* Gabb.

In the winter of 1903–4 Steinmann made some collections in the Cordillera east of Lima and from the Island San Lorenzo in front of Callao. This material was studied by Neumann, who also included some fossils in the Hamburg Museum, from Lucha, and the quebrada of Huallauca, in the Province of Ancachs. In his report (1907) he says that up to this time the Cretaceous was very incompletely known and that according to his knowledge no lower Cretaceous had been found. The fossil plants from San Lorenzo, studied by Neu-

[a] Bulletins Nos. 10, 19, 21, 25, 35, 51, dealing with the Provinces of Cajatambo, Cajabamba, Pataz, the district of Morococha, the Provinces of Jauja and Huancayo, and the Province of Huamachuco, respectively.

[b] Apuntes sobre el distrito mineral de Yauli, Annales de Const. Civiles y de Minas del Peru, Tome III, 1883.

[c] Pseudo-ceratites of the Cretaceous, U. S. Geol. Survey Monograph XLIV, 1903.

[d] Bol. de Cuerpo de Ing. de Minas del Peru No. 18, E. A. V. de Habich.

[e] Bol. No. 6.

[f] Bol. No. 31.

[g] Bol. No. 32.

[h] Bol. No. 17, Los Tigillites del Salto del Fraile y algunos Sonneratia del Morro Solar. Carlos I. Lisson.

mann, were found to be Neocomian (Wealdan) flora. The fauna from San Lorenzo was also referred to the Neocomian. The fauna from Huallauca, Lucha, and Chaco was found to be Albien, with the Rotomagien (?) lower Cenomian also represented at Huallauca. The Santonien was determined at Abra de Charata (between Oroya and Tarma), and from Lucha and Huallauca and Le Quinua. The rich material described increased the number of Senonian fossils from Peru and contained some entirely new forms, while the Wealdan flora was the first found in South America.

It will be remembered that Steinmann (1906) has referred to the Cretaceous the Puca sandstone formation, so named by him and which includes the Cora-Cora copper mines of Bolivia. This has already been discussed under the heading of the Permian. The Puca sandstone extends into Peru.

TERTIARY.

Marine Tertiary of the Pacific coast.

The marine Tertiary of the southern coastal plains was described by Forbes (1860), who called it the "Tertiary and diluvial formation of the coast." This formation is also shown in the section by d'Orbigny (1842) and by Pissis (1856), who, however, did not devote much attention to it. According to Forbes the Tertiary extends inland from the stretch of low coast lying to the north of Arica, forming gently sloping plains which show evidence of ancient sea beaches. The plains are composed of sand, earth, and gravel, with abundant fragments of porphyritic rocks from the mountains to the east. Forbes mentions a trachytic volcanic formation seemingly contemporaneous with the plains formation, which appears to have been deposited while they were still under water. This volcanic material is in the form of tuffs and ashes and has subsequently been covered by other deposits.

In discussing the saline deposits of the coastal plains (especially in territory that now is in Chile) Forbes advances the idea that with the exception of the boracic-acid compounds, the presence of which is due to volcanic causes, all the salines are such as would be left by evaporating sea water or by mutual reactions of saline matters thus left. This lacustrine hypothesis he applies to the nitrate deposits and states that the chain of hills to the west is such as might on elevation have inclosed a series of lagoons in tidal communication with the sea. For the saline deposits at high elevations he includes the factor of rainfall and states that they are not so characteristic of the lagoon type as the lower deposits near the coast.

The next reference to the Tertiary of the coast is concerning the formations in the northern coastal plains. Among the fossils sent

by Raimondi to Gabb there was a collection from Payta. Gabb, in addition to describing them (1869), states that one set of four or five specimens was made up of extinct forms, while the remainder appeared to be Pliocene.

Orton (1870) mentions some fossil shells of living species which he collected from the bluff at Payta and which were determined by Gabb.

The portion of the Tertiary formations of the northern coastal plain lying between Payta and the Ecuadorian frontier was explored and described by Grzybowski (1899). He traveled from Payta to Talara, thence to Tumbez, and up the Tumbez River to Casadero, from which place he returned to the coast. He made the following divisions of the Tertiary:

Pliocene	Conglomerate	Payta formation.
Upper Miocene	Brown shales	Talara formation.
	Sandstone	Zorritos formation.
Lower Miocene	Bituminous shales	Heath formation.
Oligocene	Hieroglyphic and massive sandstone	Ovibos formation.

He collected and described fossils from these formations. The Oligocene, however, he distinguished more from stratigraphic relations than by fossils. The paper is accompanied by a sketch map and sketch sections showing the localities where the formations were found. He observed a granite outcrop at Rica Playa, on the Tumbez River, and called certain rocks in the region of Casadero Paleozoic, but did not identify them by means of fossils. He regarded the Paleozoic as pushed up through the broken Tertiary. At Payta he noted a shale formation (no fossils) on which the Tertiary rests.

Lacustrine Tertiary of the Sierra.

In the Bolivian Plateau d'Orbigny (1842) described an ancient alluvial and pampean formation, the relations of which are shown in the section accompanying his report. Pissis (1856) also showed this formation but with an interbedded stratum of volcanic tuff in the Titicaca basin region.

Forbes (1860) described the same deposits under the name "Deluvial of the Interior" and explained that it varies from place to place according to the rocks from which it is derived. In his section he shows locally a bed of trachytic tuff and explained that it is seen in the valley of La Paz, in Bolivia.

Agassiz (1876), in the paper accompanying his hydrographic sketch of Lake Titicaca, noted the lake deposits in the Titicaca basin and said that there are terraces up to 300–400 feet above the present level of the lake, and made some comments as to its former exten-

sion when at that stage. The most definite of these comments is, that in the direction of Pucara (to the northwest) the lake reached to Sta. Rosa. He also remarked that Tiahuanaco, which is a ruin of a temple older than the Inca civilization, is 75 feet above the present level of the lake. From this we may judge that since the Indo-humanic period, as recorded by the oldest monuments in the region, the lake has not fallen more than 75 feet.

In journeying to the departments of Huaucavelica and Ayacucho, Crosnier passed through the valley of Jauja, where he found a formation which he considered (1852) to have been formed in an inter-Andean lake about 30 miles long and from 9 to 12 miles wide. The deposits are described as consisting of clays and gravels such as would have been transported by streams. He estimated the thickness at from 600 to 700 feet (200 to 300 meters). In the basin of Ayacucho he also found a Tertiary deposit consisting of marls and tuffs. No proof as to the age of these beds was given, but they were classed as Tertiary from their general relations.

In his bulletin on the Mineral Resources of the Provinces of Jauja and Huancayo,[a] Dueñas (1906) says that the valley of Jauja was in former times the bottom of a great lake, which, by cutting the canyon which is its natural outlet, has gone dry. The lake deposits he considered to be of glaco-fluvial origin. He published two photographs of river terraces cut in these deposits. Dueñas does not refer to the description of the lacustrine formation by Crosnier, with which he no doubt was familiar. The action of glaciers in connection with fluvial action brings in a new factor to explain the origin of the beds. The author has seen a portion of the Jauja Valley, and is inclined to doubt that glaciers contributed directly to form the deposits, although products of glacial action were undoubtedly brought in by rivers. If, however, lake beds were all deposited during the glacial period we must refer them to the Pleistocene of the Quaternary and not to the Tertiary, as was done by Crosnier. This is a matter for further study.

To the northwest of the Titicaca Basin, Dueñas (1907) observed certain deposits in the Department of Cuzco,[b] which he says are probably of lacustrine origin. They occur at several localities, differing considerably in character. He mentions beds of tuffs and a stratum of tripoli, in which he reported finding sponge spicules. Because of finding these spicules he says that one might be induced to suppose that in Tertiary times southern Peru was under the Pacific Ocean. This is an unfortunate remark, since it is liable to be perpetuated in the literature by being quoted without questioning whether spicules

[a] Bol. del Cuerpo de Ing. de Minas No. 35.

[b] Aspecto Minero del Departmento del Cuzco, Bol. del Cuerpo de Ing. de Minas del Peru No. 53. Enrique I. Dueñas, 1907.

of marine sponges are actually present in the deposits. Although Dueñas finally accepts the lacustrine theory for the deposits, he goes rather far when he remarks that it is nothing wonderful to suppose that Lake Titicaca once extended into the Department of Cuzco. From what the writer has seen of the topography it appears altogether improbable; and, moreover, the theory of local lakes would account in a more satisfactory manner for the occurrence of the formations.

Tertiary of the Amazon region.

James Orton, in his explorations of the upper Amazon Valley, collected some shells from Pebas, which he submitted to Gabb, who determined them (1868) as late Tertiary. Because of the finding of these shells, Orton refuted the theory of the glacial origin of the clays of the Amazon basin presented by Agassiz and discussed later in this report. Orton (1870) gives a description of the exposures along his route of travel. He says that along the Napo River the only spot where the rocks are exposed is near Napo village, where there is a bed of dark slate dipping east. Farther west, at the foot of the Ecuadorian Andes, the prevailing rock was found by him to be mica schist. The entire Napo country is covered with an alluvial bed on an average 10 feet thick. The formation of the bluff near Pebas he described as consisting of fine laminated clays of many colors, resting on a bed of lignite or bituminous shale and a coarse iron-cemented conglomerate.

After Gabb described the collection of shells from Pebas, a larger collection was made by Mr. Hauxwell, a part from Pebas but most of them from 30 miles below Pebas, at Pichua. Among them Conrad found (1870) seven species of Pachydon (Gabb), a genus which does not have any living representative and is very different from any existing fresh-water genus. He says that it is not possible to state without doubt what the relative stratigraphic position of the group may be, but if all the species are extinct it can not be later than Tertiary, and that it may have lived in fresh or brackish water, but it is certainly not of marine origin.

A collection made by Mr. Steere at Pebas was examined by Conrad (1874), who questioned there being evidence of the marine origin of the shells.

QUATERNARY.

Pleistocene glaciation.

Occurrence of Snow Peaks.

Humboldt, in his personal narrative (1811), called attention to the absence of snow peaks between the Nevada Huaylillas in latitude 7° 55′ and Chimborazo in Ecuador.

Raimondi (1873), in speaking of the Cordillera Occidental, says that snow peaks are numerous in southern Peru, but that the most colossal and gigantic are those in the portion known as the Cordillera Blanca, in the Department of Ancachs. Cerro Hundoy, in front of Caraz, is 6,828 meters high, while the bicuspate mountain Huascan, which dominates Yungay, rises to an elevation of 6,668 meters in its northern peak and 6,721 meters in its southern peak. This is near the northern termination of the perpetual snow. He also states that Huaylillas is the most northern snow peak in Peru.

In the Cordillera Central and likewise in the Oriental there are snow peaks which are mentioned by many writers, but thus far no special study of the distribution of the perpetual snow has been made.

The Lower Limit of Perpetual Snow.

Pentland (1830) made numerous observations as to the occurrence and lower limit of perpetual snow in southern Peru and in territory which is now in Bolivia. He placed the limit at 17,061 feet, and arrived at the conclusion that it is higher than would naturally be expected and especially when compared with peaks nearer the Equator. He attempted to explain this anomaly as due to aridity and excessive evaporation. Raimondi (1879) has given 14,700 feet as the average of the lowest limits in the Department of Ancachs. In the Cordilleras, in the southern part of Peru, he places the limit at 15,100 feet or more. He commented on the previous observations and explained that there seems to be a considerable error in Pentland's determinations of altitudes and considers the deductions from them as erroneous. Raimondi gives the following table of the generally admitted elevation of the lower limits of perpetual snow:

	Meters.
0°, or at the Equator	4,800
20° south	4,600
45° south	2,500
60° south	1,500

Glaciation.

After examining the evidences of glaciation in Bolivia and southern Peru, Hauthal[a] (1906) in a short notice gave as his opinion that climatic conditions similar to those of the present prevailed during the glacial period, but that a lower temperature, due to cosmic causes, gave rise to glaciers from certain centers, and that there was no general glaciation.

Dueñas (1907), in his report on the Department of Cuzco, examined the glaciated mass of igneous rock known as the "Rodadero" on the

[a] Quartare vergletscherung der Anden in Bolivien und Peru, Zeitschrift für gletscherkunde, Band I, Heft 3, September, 1906, p. 203.

hill above the town of Cuzco, and expressed his opinion that the whole valley in which Cuzco lies was occupied by a glacier. The evidence given for so great a glacier is not quite so complete as might be wished, at least its lowest limit should be determined. According to Dueñas the elevation of the Rodadero is 3,900 meters; the present limit of perpetual snow in that region is at 4,300 meters, and Cuzco is at 3,450 meters.

Undoubtedly the limit of perpetual snow was much lower during the glacial period. Just how much lower, is a question deserving of study. Raimondi has noted (1873) the occurrence of moraines much below the present snow line in the Cordillera Blanca.

At many places near the snow fields abandoned cirques may be seen below the limits of the perpetual snow and the diminutive glaciers of the present time. The writer has studied the glacier beds and moraines in the vicinity of Poto to the north of Lake Titicaca in the Cordillera Oriental and has estimated that in the glacial period the ice fields extended about 2,500 feet lower than the present glaciers.[a]

Recent elevation of the coast.

Obervations at San Lorenzo Island by Darwin.

In 1835 Darwin visited Peru and landed at Callao, but because of the troubled political condition he saw but little of the country. He reported finding on San Lorenzo Island, in front of the bay, three obscure terraces, the lower one of which, at a height of 85 feet above the sea, is covered by a bed a mile in length almost wholly composed of shells of 18 species now living in the adjoining sea. He found a bed of more weathered shells at an elevation of 170 feet. Among the shells at 85 feet above the sea he found some thread, plaited rushes, and the head of a stalk of Indian corn. From these facts he concludes that within the Indo-human period there has been an elevation of 85 feet. [These observations by Darwin have been often quoted, and only last year an excursion composed of professors and students from the School of Mines at Lima visited the island to study these terraces, and failed to reach a definite opinion in regard to the value of Darwin's conclusions.]

Observations at San Lorenzo Island by Dana.

Fortunately, the views of Darwin have been competently criticized by Dana, who (1840) visited the locality as a member of the Wilkes

[a] In northern Bolivia Arthur F. Wendt has observed that the glaciers of Illimani and Sorata have their lower termination at an elevation of about 18,000 feet, and that the ancient glaciers reached down to 15,000 feet. (Proc. Amer. Inst. Mining Eng., 1890, vol. 19, p. 85.) Agassiz (1868), it will be remembered, regarded the clays and superficial deposits of the Amazon Valley as glacial deposits, but later recognized his error.

expedition. His writings on this question seem to have been overlooked, or are at least not so well known as those of Darwin. He doubts the conclusions of Darwin, and says that the San Lorenzo shells are in an irregular bed and not stratified, but are spread out just underneath the soil, and, moreover, there is an absence of an inner cliff on the island, and nothing was seen which could confidently be referred to as terraces. He studied the sea cliff on the front of the delta formation to the south of Callao at a place where it is from 45 to 65 feet high. In this cliff he found remnants of trees and, in an upper layer, comminuted recent shells. He regards this cliff as furnishing evidence of an elevation since the beds were deposited, but says that to fix the time may require some further attention than the facts observed.

Prehistoric Indian Village at Ancon.

A short distance to the north of Callao is the small port of Ancon. Archeologic researches have made known to us the very interesting remains of a fishing town of at least great antiquity. These remains and especially the interred mummies are but a few feet above the present beach. The proximity of Ancon to Callao precludes the probability that an elevation of the coast at Callao which would have raised San Lorenzo Island 85 feet would not have affected Ancon, and the writer wishes to adduce this as the most definite proof obtainable that the coast in that vicinity has remained nearly stationary during the Indo-human period.

Observations at Arica by Lieutenant Freyer.

In a letter to Charles Lyell,[a] Lieutenant Freyer says that to the south of the Morro of Arica, on indistinct terraces, wherever the rock is exposed there are Balani and encrusting Millepora, and that at a height of about 20 to 30 feet they are as abundant and almost as perfect as at the shore. At upwards of 50 feet they still occur, but are abraded by the blowing sand, and there are traces of them at still greater heights.

Observations at Arica by Forbes.

From Mejillones, in Chile, northward to Arica Forbes found at intervals shell beds containing exclusively shells of species now inhabiting these waters. These shells are at small intervals above the sea, but do not reach a height of 40 feet. He stated that he was not successful in finding Balani and Milleporas attached to the sides of the Morro of Arica, and argues that no very perceptible elevation

[a] Geol. Proc., Vol. II, p. 179, published 1835.

can have taken place during three hundred and fifty years as is shown by the position of Indian tumuli. He called attention to how shells may be transported inland by human agencies, by birds, winds, and drifting sands, and advises caution in accepting the mere presence of shells as a proof of elevation.

OBSERVATIONS IN NORTHERN CHILE BY ALEXANDER AGASSIZ AND L. F. POURTALES.

In line with the statements by Lieutenant Freyer it may be noted that in northern Chile, in a ravine 20 miles inland from Pisagua at Beringuela (at Tilibiche), at an elevation of 2,900–3,000 feet, "recent corals" were found by Agassiz, who says that they indicate an inland sea connected with the Pacific Ocean, and that there is accordingly reason to believe that the continent has been raised "within a comparatively recent period."

The corals were described by Pourtales. It is stated that they were fossilized into a compact limestone and consisted of two new species. One was referred to a genus not represented in any lower strata than the Tertiary, and is not now living on the Pacific coast of America. The other species was referred to a genus which had up to that time been described only from Jurassic and Triassic formations.

The writer wishes to call attention to the fact that the fossils do not date the "comparatively recent period" and do not furnish evidence which is more convincing than the relations of the Tertiary sediments, which are widely distributed in the coast region.

RAPID RECONNAISSANCE OF THE TERTIARY AND QUATERNARY OF THE COAST.

The writer in traveling through the coast of Peru studying the geology in relation to the underground waters, observed the occurrence and distribution of the Tertiary formations in so far as was possible in the time allotted to his work, and has outlined the occurrence of the formations in the bulletins by him published by the Corps of Engineers of Mines of Peru. From what he has written the following summary, which includes a few modifications, is presented with the hope that future observers may use it to correct and amplify a knowledge of the subject.

TERTIARY OF THE NORTHERN COASTAL PLAIN.

The Amotape formation.

This name was given to the formations which are exposed near the village of Amotape, which is situated in the valley of the Chira River and is particularly well seen in the western end of the Brea

or Amotape hills (see pl. 2). The lithologic characters of the beds vary considerably, consisting of shales, sandstones, conglomerates, and in some places beds filled with shells and occasionally there are coral reefs. The changes observed in the nature of the formation are due to the varying distance from the shore at which they were deposited and to the deepening and shallowing of the water during the time of sedimentation. It is probable that the materials were derived from the mountainous area which during Tertiary time formed the ocean shore to the east, approximately where now are the foothills of the Andes.

The strata of the formation are not much lithified and the shales and sandstones grade into each other and into conglomerates. In the Brea hills the Amotape formation has been uplifted in an anticline, giving good exposures where the stream valleys have been eroded. The thickness of the beds has not been studied carefully, but from the outcrops seen it is safe to say that on the average it is not less than 1,000 meters, although the thickness may be much less in some places and greater in others, depending upon the distance from the Tertiary shore.

Fossils are very abundant and well preserved at many places, one of the most noticeable being a large oyster which is found in such great numbers that it is used locally for burning lime.

The principal mineral substance which is exploited at the present time is petroleum, of which there are superficial indications at two places called la Brea and la Breita. The productive localities are Negritos, Lobitos, and Zorritos located on the coast. Besides these some prospecting has been done farther inland. It has been reported that coal has been found at various localities within the limits of this formation. That which the writer examined at Bahia de la Cruz is a lignite, and prospecting failed to reveal a bed of any importance. The writer has been assured that north of Sullana, at the base of the Brea hills, a good quality of lignite has been found and of sufficient thickness to warrant its extraction. However, the bed has never been worked and further exploration would be necessary to prove its commercial value. The Amotape formation contains various mineral salts, especially gypsum, which render the water obtained from it unfit for domestic uses. The formation extends throughout the plains region from the Ecuadorian border southward into the table-land to the east of Pita. Undoubtedly it extends farther south, but the exposures are obscured by drifting sands and have not been studied by the writer. It may be noted in this connection that Wolf in his geologic map of Ecuador has erroneously indicated a recent formation in the plains region to the north of the Brea hills.

In the Brea hills the formation has been thrown up in an anticline. To the south in the plains region the formation is relatively horizontal. To the north of the hills there are steep dips and local folds. These may be well seen along the valley of the Tumbez River and in the stream which empties into the ocean at Boca de Pan. It is interesting to note that the direction of the Brea hills is almost at right angles to the trend of the Andes and parallel with the border of the Gulf of Guayaquil and with the coast of the Province of Tumbez, which forms the southern part of the Gulf of Guayaquil. Moreover, the direction of the dips to the north of the range of hills suggests that the folding which produced them was actuated from the north.

The writer has not examined the axis of the range, but has been assured by travelers that it contains igneous rocks. Where the Tumbez Valley merges from the flank of the hills there are some exposures of granite, which the writer saw and the presence of which was also noted by Grzybowski, but this granite may be older than the Tertiary. The anticlinal structure of the range of hills may be due to the eruption of igneous rocks which form the axis, but the writer did not see anything to indicate this at their western termination, and he is inclined to believe that it should be correlated with the subsidence which produced the embayment of the coast in the region of the Gulf of Guayaquil.

Grzybowski was the first to study the Amotape formation, and what the writer has included under the name "Amotape formation" has been divided by Grzybowski into the Heath stage, which he calls "Lower Miocene," and above it the Zorritos and Talara stages, which he calls "Upper Miocene." He also identified, principally upon stratigraphic grounds, the Ovibos stage, which he refers to the Oligocene. The exposures which he included in this stage have not been seen by the writer, who regrets that he did not have access to Grzybowski's paper until after his own manuscript was written. It will be remembered that Raimondi sent some fossils from Paita to Gabb for determination; the localities from which they were collected were unfortunately not sufficiently specific to show whether they were from the Amotape formation or not. A collection of fossils from Zorritos was also described by Nelson, who made no special determination of their age other than late Tertiary, as suggested by the title of his paper.

Pliocene formation at Paita.

In the sea cliff at the port of Paita the writer observed two formations separated by an unconformity. The lower he considered to be the Amotape. The upper consists principally of sand in imperfect sandstone. When he boarded the steamer in the bay the writer made

a sketch (fig. 5) of the relation of these two formations, and upon sailing southward made a similar sketch (fig. 6) showing the relations of the bed as seen after rounding the point. The presence of the bubonic plague at Paita during the writer's visit, and especially the establishing of the hospital to the west of the town, prevented a thorough examination of the locality. Grzybowski, in his article, mentions some shales cut by minute quartz veins which he found outcropping to the west of Paita near Paita Point. These shales, which were not well seen by the writer, were included by him in his sketch as a part of the Amotape formation. The division between the Amotape and upper formation shown in the sketch corresponds approximately with the dividing line between the shales and sandstones of Grzybowski's section at Paita[a] (fig. 7). Grzybowski has described what he calls the "Paita stage" from the locality at Paita, and if it had not been for this the writer would apply the name Paita formation to the upper one, which he has differentiated.

FIG. 5.—Section of sea cliff at Paita.

The age of the beds at Paita was not well determined by the fossils which Gabb received. He states that some of the fossils were extinct forms, and that the remainder appeared to be Pliocene. Grzybowski assigned the Pliocene age to his Paita stage. The writer thinks that the unconformity which he has shown in his section is unmistakable, and that accordingly he would call the upper beds Pliocene. The extent of this formation has not been determined with certainty, but it apparently occupies the upper portion of the table-land of Paita. To the north, in the plains around la Brea hills, it is not to be found in extensive areas, since the good exposures which were seen all belong to the Amotape formation. The Brea hills were perhaps above the level of the sea during the time it was deposited. It may be more appropriately expected southward, underlying the desert of Sechura.

FIG. 6.—Section of sea cliff to west of Paita.

[a] Original figure in Neues Jahrbuch für Mineralogie, Beilageband XII, Pl. XVI, fig. 1.

TERTIARY OF THE SOUTH CENTRAL COASTAL PLAIN.

The Pisco formation.

In the low hills to the north of Pisco, which is called "Cerro de Tiza" (meaning chalk), there are exposed white and yellowish rocks which have a calcareous aspect much like chalk (see pl. 4). At the end of the bridge over the Pisco River they may also be seen, and at this place they have steep dips and strike to the northwest. This structure is continued into Cerro de Tiza, and crosses the Pisco River to the south until the rocks disappear beneath the sands of the plains toward Ica. Many outcrops of this formation may be seen, especially in the landscape to the south of the railroad station at mile 18, but there the beds are practically horizontal. In the Ica River valley the same formation is found resting on igneous and older stratified and metamorphic rocks. In a hill to the west of the Hacienda Ocucaje, in a hill called "Cerro Blanco," the writer saw the remains of a whale embedded in the Pisco formation. There

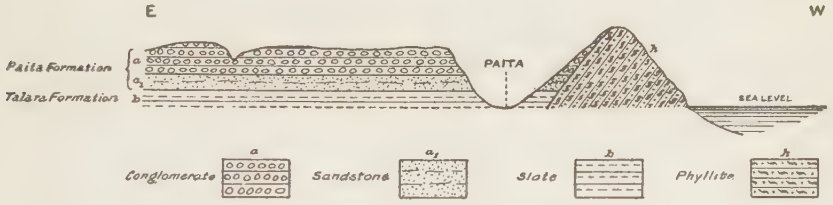

FIG. 7.—Section at Paita, by Grzybowski.

was also some strata in which a few marine shells are found and others in which phosphate nodules occur, but to an extent so limited that they have no commercial value. Farther south in the valley of the Rio Grande the Pisco formation is cut by the canyon of that river. The tributaries of the Rio Grande which flow past Palpa and Nazca have cut deep valleys, in the walls of which the formation is seen to contain a mixture of rounded stones in a matrix of sand and clay materials, but with a sufficient amount of the white chalky matter which characterizes the formation to demonstrate that it is only a littoral phase of the Pisco formation.

The Pisco formation is also found in the plains to the east of the port of Lomas, where the remains of a whale were seen by the writer, and in one of the valleys which cut the plain a conglomerate of marine shells was found. To the southward the plains narrow and the mountains come to the seacoast, but at Chala there is a small area of Pisco formation in which the beds consist largely of variegated clays.

In the northern part of the plains, to the east of the Cañete, the Pisco formation was found presenting a littoral phase, but containing

some of the white chalk material and some beds of impure concretionary limestones similar to what occurred at the type locality near Pisco. The so-called chalk material was analyzed by the Corps of Engineers of Mines and found to consist principally of silica, with small amounts of lime and alumina. A microscopic examination showed it to contain many diatoms and what appeared to be volcanic ash.

In traveling by steamer from Pisco to Lomas the Pisco formation can be seen forming the sea cliffs and rising to the table land of Ica.

Although some fossils have been found, they have not been studied critically. The age of the Pisco formation is not surely known. The writer has assigned it to the Pliocene provisionally, since it is overlain by deposits which are probably of Pleistocene age, and there is no information which shows the necessity of assigning it to an earlier time.

TERTIARY OF THE SOUTHERN COASTAL PLAINS.

The Moquegua formation.

The writer has given this name to the formation which occupies the southern coastal plains. It has been described locally, by Forbes and others, as already mentioned in this paper, but no one had journeyed sufficiently over the plains to learn that it was coextensive with them. The strata which constitute it can be studied conveniently in the valley of the Moquegua River, especially near the town of the same name. It is also well exposed in the valleys of all the streams which cross the plains, since they have cut deep canyons. The eastern limit of the formation is at the foothills of the Andes, and the western limit is formed by the chain of coast hills. It reaches to the Pacific Ocean in the interval between the coast hills of Peru and the Morro of Arica, which is the northern extremity of the coast hills of Chile. The character of the rocks which constitute the Moquegua formation has been well outlined by Forbes. They consist of sands with some clays, a large quantity of detrital material derived from igneous rocks, but especially noticeable are the thick beds of volcanic material which appear to have been deposited in water and interbedded with sands. In the valley of the River Vitor, which descends from the Andes past the volcano Misti which is located near Ariquipa, beds of lava may be seen which have descended from the volcano and extended over the plains, where they form a capping on the Moquegua formation. The age of the volcanic rocks is not certainly known, and there has been no opportunity to determine the age of the Moquegua formation, since no fossils have been found. It is generally stated that the volcanoes of southern

Peru began their activity in Tertiary times and some of them are still active, although no great lava flows have come from them in recent times. The writer has provisionally assigned the Pliocene age to the Moquegua formation, thus making it contemporaneous with the Pisco formation to the north. There appears to be no reason for considering it as of greater age, and in outlining the history of the coast the Pliocene age seems for the present satisfactory.

The thickness of the Moquegua formation is variable, since it was apparently deposited in a trough between the coast hills and the foothills of the Andes (see fig. 8). From measurements made in some of the canyons a thickness of 1,500 feet may be assigned.

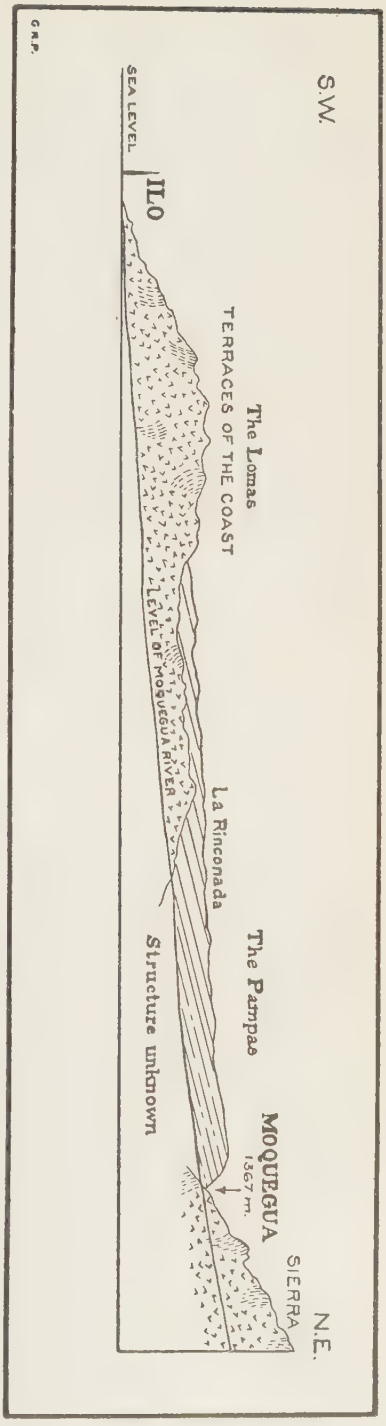

FIG. 8.—Section showing relations of the Moquegua formation.

QUATERNARY DEPOSITS.

Pleistocene.

THE PACASMAYO FORMATION.

At Pacasmayo, in the southern part of the northern coastal plains, the sea cliff consists of stratified conglomerates mixed with sand and occasional clay beds (see pl. 3). The formation is also well exposed at the mouth of the Jequetepeque and along that stream inland. At Eten the sea cliff consists of a homogeneous sandy clay. To the north of Eten for a considerable distance the coast is low near the shore and there are no good exposures, so that the writer has not been able to trace the Pacasmayo formation

FIG. 9.—Section correlating the formations of the coast.

farther in that direction. To the south of Pacasmayo the coastal plains narrow until the mountains descend to the shore south in the valley of Viru. Throughout this extent the Pacasmayo formation is represented in its various phases. The age and relations of this formation will be more clearly understood when it is considered in connection with the Barranco formation next to be described, with which it has been correlated (see fig. 9). It is to be regretted that in the region of the Sechura desert the relations of the Tertiary formations of the northern part of the northern coastal plains and the Pacasmayo of the southern portion are obscured by the drifting sands, which obliterates any exposures which might otherwise be seen in this area of slight relief.

Barranco Formation.

At the valleys of the Pativilca, Huaura, Chancay, and Rimac rivers there are sea cliffs cut in what appear to be raised delta formations. In other valleys to the south and north smaller areas of a similar formation may be seen (see pl. 4). At Tambo de Mora the sea cliff has the same character as at the mouths of the rivers, but there the formation extends inland and northward continuously to the valley of the Cañete. The writer regards this area, which constitutes a part of the south-central coastal plains, as furnishing the key to the proper understanding of the Barranco formation. It undoubtedly lies upon the Pisco formation, although its relations to the latter south of the Chincha River are not very clear because of the intervention of the wide stream valley. Its relation to the Pisco formation may also be seen in the Cañete Valley. The character of the materials and the degree of cementation in the Pacasmayo and Barranco formations is similar.

No fossils have been found with the exception of comminuted shells and occasional branches of trees. The writer has assigned the Pleistocene age to these deposits and would correlate the coarse sediments and bowlders which have been deposited in the form and structure of deltas with the in-

creased volume of the streams and the erosion which accompanied the glacial period.[a]

RECENT FORMATIONS OF THE COAST.

The recent formations consist principally of materials transported by the rivers and deposited at their deltas and of the wind-blown sands which sweep over the coastal plains. In addition there are places along the coast where the materials eroded by wave action and transported by ocean currents have accumulated in the form of recent beaches. The beaches here referred to should not be confounded with the raised beaches, which will be discussed later in this paper. The deltas of the coast are usually unsymmetrical because of the northward direction of the coast currents. In many cases the deltas blend with the recent beaches, due to marine action. The delta of the Tumbez River, which is the northernmost of the coast, lies in front of a clearly defined sea cliff. Similarly the delta of the Chira River blends with the recent sea beaches lying in front of a sea cliff, which extends from the mouth of the river northward to Negritos.

The remaining rivers of the northern coastal plains do not have deltas worthy of special mention. In the extent of mountainous coast between the northern coastal plains and the south central coastal plains there are a number of localities where recent beaches may be found, and in this part of the coast the Quaternary and Tertiary deposits already described are absent.

To the north of the Santa River there is an area of recent beaches in which salt is manufactured by evaporation, the brine being obtained by digging shallow pits, into which it filters. The area of the beaches is extensive, and the slight depth to the salt water indicates the fact that they are but slightly above sea level. The materials which have accumulated and formed the beaches have largely been brought by the Santa River and drifted northward by the ocean currents. The immediate delta of the Santa River has extended seaward and so connected an island with the mainland. In Chimbote and Samanco harbors one may see an area of drowned mountainous coast. At some former time the two bays were one, but the accumulation of sand has formed a bar and connected one of the larger islands with the mainland. The front of the raised delta of the Rimac River, on which Lima, the capital of the country, is located, has been largely cut away by marine erosion, and the currents have drifted the materials northward, forming the spit of land called la Punta, which is a feature of the harbor of Callao. This spit is

[a] A description of the Rimac delta by the author may be found in Bulletin No. 33 of the Corps of Engineers of Mines of Peru, published in 1905.

gradually extending, and lying between it and the island of San Lorenzo there is now a bank on which the waves break. The ultimate outcome of this process may be a connection between the mainland and San Lorenzo Island.

At Port Cerro Azul the rocky promontory which protects the port was once an island. It has been connected with the mainland by the growth of the delta of the Cañete River. Similarly there are a number of delta deposits and recent beaches in the southern part of the coast. In riding on a train from Mollendo along the beach before the ascent of the range of coast hills is made one may see recent conglomerates, which have been partially eroded, and marine beaches in process of formation.

The material transported by the winds has in places accumulated in areas of sand dunes which are moving with the general direction of the wind, but the more common condition is to find the sand forming a mantle on the hill slopes and rounding the contours of the hills, and often rising well up on to the sides and in some cases even to the crests of the mountains. The most extensive area of drifting sand is to be found in the Sechura Desert and the plains to the east of Piura. In the latter place the sand is held by a sparse growth of drouth-resisting trees and bushes. The height of this drifting sand as seen in the topography of the country reaches perhaps 200 feet, but proof of its great thickness was obtained when a well was drilled in it. The drillers could hardly be expected to distinguish the point at which they passed out of the wind-drifted sand, but they found nothing but sand and had no difficulty in driving the casing of the well to a depth of something over 3,000 feet.

If one refers to the map of the coast of Peru and observes the configuration of the coast in the region of the desert of Sechura, he will see that the direction changes more to the west so that the winds blowing from the Pacific have a clean sweep over the desert, and the sand is carried inland by the winds in a nearly northern direction. It is this fact which accounts for the low relief near the coast where the sand has been derived and the great thickness of the Aeolian deposits to the east of Piura.

In the south central coastal plains there is a conspicuous area of sand hills between Ica and Pisco; also some smaller ones to the west of Ica and Palpa. There are numerous areas of migrating sand hills in the southern coastal plains, but none of the dunes attain great altitudes, the surface of the plain is hard and the sand moves in crescentic dunes as over a floor. These dunes may be seen from the railway in traveling from Mollendo to Ariquipa and are one of the sights usually remembered by the traveler. Mixed with the sand which drifts over the southern coastal plains there is a large amount of white volcanic ash or sand derived from volcanic materials.

RAISED BEACHES.

The action of the sea in cutting cliffs may be well observed along the coast of the northern coastal plains, where the Tertiary formations at many places rise in sheer bluffs. The same process has been in operation at other places on the coast where elevation has taken place and the cutting action of the sea is displayed in a succession of marine terraces. These are especially noticeable on the coast between Pisco and Lomas, where the Pisco formation displays approximately ten distinct terraces rising to a height of perhaps 1,000 feet. Along

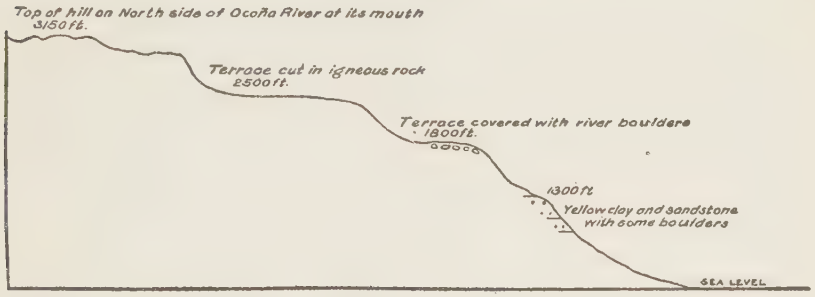

FIG. 10.—Section showing marine cut terraces at the mouth of the Ocoña River.

the southern part of the Peruvian coast in front of the range of coast hills where the rivers have cut their canyons through, there are terraces in the igneous rocks which constitute the hills and also in the remnants of what were once delta formations of these streams. The terraces at the mouth of the Ocoña River, as seen by the writer and measured with an aneroid, are represented in the following sketch (fig. 10). The upper terrace at Ocoña is the highest one which was found on the coast.

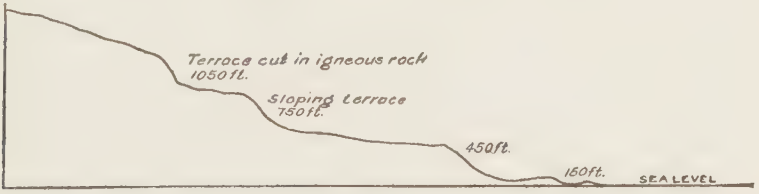

FIG. 11.—Section showing marine cut terraces at the mouth of the Ilo River. (Compare fig. 8.)

The railroad station, Tambo near Mollendo, on the Southern Railway, has an elevation of 1,000 feet and is situated on the north side of the River Tambo near its mouth, on an extensive terrace which must have attracted the attention of many travelers, although its origin is not explained in any scientific article which has come to the writer's notice.

The terraces south of the Ilo River, near its mouth, are indicated in the above sketch (fig. 11).

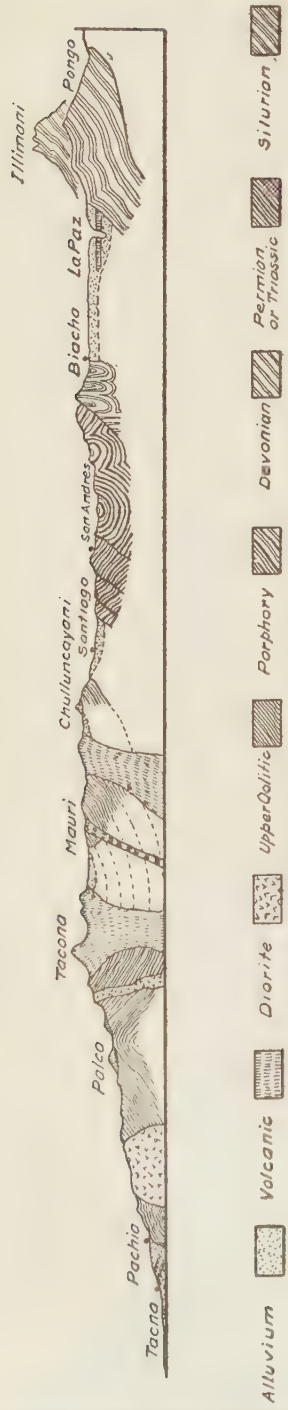

Fig. 12.—Geologic section from Arica to La Paz, by Forbes.

Incidentally it may be said that at the mouth of the canyon just north of Pisagua in Chile similar terraces may be seen, the upper one being at an elevation of something more than 1,000 feet.

These terraces, taken together with the elevation at which the Pliocene Tertiary formations on the coast are found, record the rising of the land. Accordingly, the upper terraces may be Pleistocene and the lower ones Recent, but there is nothing to indicate two periods of movement, and the spacing and disposition of the terraces cut in the Pisco formation indicate a gradual elevation.

Geologic Sections of the Andes.

Section of southern Peru, Arica to La Paz, by David Forbes (1860).

If the general section of Peru by Forbes[a] (fig. 12) is divided so that it may be compared with the succession of zones parallel to the trend of the Andes, as distinguished by Steinmann at a later date, the following may be enumerated from the coast toward the interior:

1. Mesozoic sediments with interstratified porphyries of the coast range (at Arica).
2. The Tertiary (and diluvial) formation of the coast plains with trachytic tuffs and ash beds.
3. The diorites of post-Cretaceous (post oolitic) age.
4. The Mesozoic sedimentaries with interstratified porphyries of the western slope of the Cordilleras cut by diorites.
5. Volcanic trachytes and trachytic rocks of the Cordillera Occidental cutting the Mesozoic sedimentaries.
6. Zone of Paleozoic (Carboniferous and Devonian) sediments of the Titicaca basin with later "diluvial," including a bed of interstratified trachytic tuff.

[a] Original in Quart. Journ. Geol. Soc. London, Vol. XVII, Pl. III.

7. Zone of slates (Silurian) and granites.

Comparing these zones with those enumerated by Steinmann, later to be mentioned, it will be seen that there are no granitic rocks in the coast and that the coast range which extends from Arica southward into Chile is not comparable with the coast range at Mollendo. In fact, there is a gap between the two just north of Arica. In other respects the zones are quite comparable excepting for the difference due to the structure of the Titicaca basin. The rocks which Forbes called "Permian" or "Triassic" are now called "Cretaceous" by Steinmann, and above are included with the Mesozoic.

SECTION THROUGH THE DEPARTMENT OF ANCACHS, BY RAIMONDI (1873).

It should be remembered in considering this region that the Cordillera Occidental divides into two branches, the western known as the "Cordillera Negra" and the eastern or principal one, the "Cordillera Blanca." Raimondi made no section, but from his writings one may recognize the following zones:

1. Granites and syenites of the coast.

2. Mesozoic sediments with porphyries and diorites. The sedimentaries are rare in the coast but are found more abundantly inland.

3. The diorites are seen in the Cordillera Negra and the Cordillera Blanca up to the limit of snow, but not in the crest of the range or axis. The eruption of the diorites posterior to the Jurassic removed and lifted some formations of the Cretaceous and introduced metallic veins.

4. Trachytes anterior to the present, there now being no volcanoes. These rocks are present in the Cordillera Blanca and to some extent in the Cordillera Negra but not forming peaks in the latter. Raimondi thinks the eruption of the trachytes occurred at a time when the two Cordilleras formed one mass and that they have since been separated by erosion.

5. In the valley of the Maranon are found older sediments, talcose slates with quartz veins which are referred to the Silurian. A small area of similar rocks was also noted at Pallasca on the western slope of the Cordillera Nevada.

SECTION OF ECUADOR, BY WOLF (1892).

Reviewing the geology of Ecuador as outlined by Wolf and coordinating the data in such a way as to compare it with the sections already given of Peru we find the following more or less distinct zones:

1. The Tertiary and Quaternary formations of the coast of marine origin.

2. The Cretaceous, principally in the western Cordillera[a] of Ecuador. This rock presents three facies: (*a*) Toward the coast and in the hills of the coastal plains, limestones, siliceous limestones, and shales with variegated sandstones and quartzites; (*b*) in the mountain basins, sandstones, and clay shales and slates; (*c*) conglomerates and breccia form conglomerates, sandstones, and clay shales predominating in the Cordillera.

3. With the Cretaceous are associated porphyries and greenstones, some being contemporaneous and others post-Cretaceous. With these igneous rocks, of which the diorites are the most common, are associated the mineral deposits.

4. The gneisses and crystalline schists of Archean age principally in the eastern Cordillera. There are granites in genetic relation with the gneisses and syenites in genetic relation with the schists.

5. The volcanic rocks which are related to the still active group of volcanoes of Ecuador. The volcanic tuffs contain bones of Quaternary mammals, but the volcanic activity may have commenced in the Tertiary.

6. Lacustrine Tertiary in some of the inter-Andean basins.

SECTION FROM LIMA TO CHAUCHAMAYO, BY GUSTAV STEINMANN (1904).

According to Steinmann there are in Peru six zones, well marked by their distinct geologic composition, which extend parallel to the axis of the Cordilleras. These zones are designated as follows:

1. The granitic-Tertiary zone of the coast.
2. The first zone of Mesozoic sediments.
3. The zone of diorites.
4. The second zone of Mesozoic sediments with a porphyritic facies.
5. The third zone of Mesozoic sediments with a calcareous facies.
6. The zone of slates and granites.

The first zone is not represented in the vicinity of Lima, but may be found to the south from Pisco to Mollendo. The granitic rocks are siluric or pre-siluric, cut by Mesozoic porphyries.[b] The Tertiary formations are probably Pliocene.

The second zone near Lima contains sandstones and quartzites, shales, and slates, with some limestones. The age of the formations is Cretaceous (Neocomian) as is shown by invertebrate and plant remains. The structure is in the form of an anticlinal fold. The sedimentary rocks are cut by dikes of porphyry.

[a] Because of the fact that the Cordilleras Oriental and Occidental in Ecuador are not the equivalents of the Cordilleras Occidental and Oriental of Peru, they are here spoken of as the "western" and "eastern" to avoid confusion.

[b] The writer wishes to suggest that the small Carboniferous area near Pisco should be included in this zone.

In order to make clear the aspects under which the porphyries present themselves, the following explanation is offered: From the close of the Triassic, during Jurassic and Cretaceous time, a shallow sea with a gradually sinking bottom occupied the region which to-day constitutes the western part of the Andes. In this sea, in which normal sediments were being deposited, immense eruptions of basic volcanic rocks occurred, taking the forms of flows, conglomerates, breccias, sandstones, and stratified tuffs.

The third, or diorite, zone is found on the western slope of the Cordillera Occidental. The diorites are clearly younger than the Cretaceous sedimentaries, since they have cut and metamorphosed them. The normal diorite contains dikes and masses of a darker, more basic, and finer-grained diorite. The Mesozoic rocks which occupied this zone have nearly all disappeared.

The fourth zone includes the crest and eastern slope of the Cordillera Occidental. Here the porphyritic facies in the Mesozoic rocks is typical. The formations, Jurassic and Cretaceous, are strongly folded, and the inclination of the beds is more frequently to the west than to the east. In this region andesitic eruptions abound (for the most part quartzitic) and extend eastward into the next zone. The mineral deposits of the region are related to these andesites.

The fifth zone in the calcareous formations gradually replaces the porphyritic facies until it becomes a great limestone formation, which, from the fossils, is shown to be of Jurassic and Cretaceous age.

In the sixth zone granite and slate are found. Although no fossils have been found in the slates, they are considered to be Silurian because of their resemblance to the known zone of Silurian in southern Peru and Bolivia.

Below the Mesozoic sediments there is a series of dark siliceous slates and sandstones, with some conglomerates, which are believed to be Paleozoic and especially Carboniferous, the existence of Carboniferous in the region being proven by finding a few characteristic fossils. Inasmuch as the Permian is not present in the Cordillera of Peru, the red sandstones and shales, with salt and gypsum, which overly the Silurian quartzites and slates, are referred to the lower Lias, no fossils having been found as yet, and they accordingly belong to the series of Mesozoic sediments.

Age of the Cordilleras and Development of the South American Continent.

In the atlas accompanying d'Orbigny's monograph there is a map of South America showing the general distribution of the geologic formations according to his ideas. The map is very conventional and is of little value to-day. The most noticeable error as regards Peru is

that he breaks the continuity of the Cretaceous in the Andes between northern Peru and Ecuador, so that the Tertiary of the Pacific coast connects with the Tertiary of the Amazon basin in the latitude of the Gulf of Guayaquil. D'Orbigny also published four small maps showing the development of the South American continent. He took as a nucleus a small area of gneissic and primordial rocks along the Brazilian coast. From this area the land mass developed to the northwest. After the Carboniferous he shows a land mass in Guiana in addition to the larger one in Brazil. After the Triassic he shows an isolated land mass in the eastern Cordilleras of Peru and Bolivia, and following the Cretaceous he unites the Brazilian and Andean land masses by a fringing border of Cretaceous, and shows an isolated mass of Cretaceous in Ecuador and Colombia and Venezuela. The remaining parts of the continent were formed by the addition of Tertiary and diluvial. [The maps by d'Orbigny are of only historical interest as showing the development of geological science at that time.]

Agassiz appears to have followed in a measure the ideas advanced by d'Orbigny. He says in substance (1868) that the valley of the Amazon was first sketched out by the elevation of two tracts of land, namely, the plateau of Guiana on the north and the central plateau of Brazil on the south. It is probable that, at the time these two tablelands were lifted above the sea level, the Andes did not exist and the ocean flowed between them through an open strait. At a later period the upheaval of the Andes took place, closing the western side of this strait and thus transformed it into a gulf open toward the east. It seems certain that at the close of the secondary age the whole Amazon basin was lined with a Cretaceous deposit, the margins of which crop out at various localities on its borders. They have been observed along its southern limits on its western outskirt along the Andes, in Venezuela along the shore line of mountains, and also in certain localities near its eastern edge.

Orton evidently followed the ideas advanced by Agassiz, but his poetical and cataclastical account of the geological development of South America is of no value to science. He says, for example: "Three times the Andes sank hundreds of feet beneath the ocean level and again were slowly brought up to their present height."

The first attempt which Raimondi made to outline the geology of Peru was in his letter to Gabb (1867). He stated that the eastern Cordillera is of greater age geologically, appearing to be composed of micaceous and talcose slates which have been metamorphosed by the elevation of the granites, that have also introduced numerous veins of quartz which in some places are quite rich in gold. The western Cordillera, he says, is made up in nearly the whole of its length of rock of much more recent age (Mesozoic). Another group

of rocks, probably Carboniferous, form the great basin of Lake Titicaca, and a small spot in the heights of Huanta.

In his volume on the Department of Ancachs (1873) he elaborates his ideas somewhat more fully. He says that the first land relief produced within the limits of Peru was not the Cordillera which forms the continental divide, but the grand mountain chain which in Bolivia forms the Cordillera real and extends northward into Peru.

This grand chain is formed for the most part of talcose and clay slates and owes its relief to the eruption of granitic rocks, which, however, did not always find their way to the surface, being rare in the southern part of the chain, but in many places the eruption introduced quartz veins into the slates. Contemporaneous with this relief perhaps occurred the eruption of the granites and syenites of the coast, which in many places contain thin veins of auriferous quartz.

After the Jurassic began the eruption of the porphyries, and when the Cretaceous had begun the grand eruption of the diorites took place. Following the deposition of the Cretaceous the axis of the Cordillera was brought into relief.

A sketch of the geology of South America was read by Steinmann before the Geological Society of America in 1891. This sketch is explanatory of a map which was prepared by him for a second edition of Berghausen's Physical Atlas. Unfortunately the map is very small, and, moreover, data were not available for an accurate map. From the sketch the following points may be gathered which are of interest here.

In Devonian times, as is indicated by the sediments, there was an extensive sea embracing the larger part of South America, especially Brazil and Bolivia (and extending also into Peru).

The Carboniferous deposits were more restricted, but are known from Peru, Bolivia, and Brazil.

During the Permian, Triassic, and Jurassic the greater part of the South American continent was above sea level; however, the Triassic and Jurassic marine deposits have been found on the western part of the continent, rich collections of Jurassic fossils having been obtained from the Cordilleras of the Argentine, Chile, and Peru.

In contrast to the small extension of marine Triassic and Jurassic the Cretaceous covers a large area, marine Cretaceous being found in all parts of the Cordillera of the Andes from Venezuela to Patagonia.

The Cordillera of South America is famous for its eruptive formations of the latest time, but it merits no smaller attention for its submarine eruptions during Mesozoic time and the injection of the Mesozoic strata by dioritic rocks.

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OUR PRESENT KNOWLEDGE OF THE EARTH.[a]

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* * * * * * *

The explorer of nature is naturally inclined to direct his search to the earth itself, on whose surface we live. He asks what secrets may lie hidden in the depths beneath our feet. My purpose on the present occasion is to set forth some of the answers which science is now able to give to that question.

The simplest method, of course, would be for the explorer himself to penetrate into the earth by the way pointed out by the miner. But this hope quickly vanishes as we survey the means at our disposal and the results thus far achieved. Mining operations extend to a depth of about 1 kilometer (3,280 feet); the deepest shaft ever bored reached a depth of about 2 kilometers (6,560 feet), and the center of the earth is 6,370 kilometers (about 4,000 miles) beneath us.

What are 2 kilometers compared to that? Imagine the earth represented by a ball 13 meters (42 feet) in diameter; then a shaft 2 kilometers (6,560 feet) deep would be represented by a needle prick 2 millimeters (about one-twelfth inch) deep! And yet the sinking of such a shaft is a work of exceeding difficulty; with every meter the difficulties increase at an accelerated rate, soon outstripping all human power.

Thus in our search into the interior of the earth, apart from a very thin superficial layer, we must depend entirely on the resources of science.

Immediately beneath us we find masses of rock; that we know for certain. But what is there farther down? Does the rock continue throughout all the depths, or shall we come to metals? Rocks are comparatively light, the metals that might be expected are comparatively heavy. Hence if the density of the earth's material is known, we

[a] Translated by permission from Deutsche Rundschau, Band CXXXII (September, 1907), Berlin, pp. 376–394.

[b] Address delivered for the benefit of the Göttingen Ladies' Union, February 14, 1907.

shall have a datum point from which we may judge. To this, science has in fact been able to supply an answer within certain limits.

The starting point of the demonstration is the law of universal gravitation. You will remember that the English scientist Newton was the first to recognize the influence of that force in the making of the world. Gravitation holds the earth together, holds us fast to its surface, determines what is "up" and "down." As the child's strength increases it must learn to stand erect in opposition to gravitation; with advancing years the old man feels more and more its down-pulling force. It compels the moon to describe its orbit around the earth; it determines the movement of the planets around the sun. Summing up his observations, Newton was led to the conclusion that all matter without exception is mutually attractive, no matter what may be the size of its particles or the distance between them. According to his law, the smaller the mass, and the greater the distance, the less is the attraction; but it never becomes zero. We are thus driven to the conclusion that the various objects which we encounter on the surface of the earth also attract each other. Is this true? In daily life, indeed, the effect is not perceptible. Your thoughts may at this moment be turning to the electrical and magnetic phenomena in which attraction is distinctly observed; but these do not belong here; they are the effects of forces quite different in their nature from gravitation. In point of fact, by means of delicate instruments it has been possible to demonstrate and measure the mutual attraction of the objects that surround us. If a body, say a metal globe or any other object, be so suspended as to be protected against disturbance, while the thread that holds it offers a minimum of resistance, and if thereupon another body, say a lead weight, be made to approach it, the suspended body will be seen to move toward the approaching body, and thus fall toward it, even though slowly, just as the apple, detached from the tree, falls to the earth. As the approaching body is small in comparison with the earth, it is to be expected that some minutes will elapse before the suspended body shows a movement of even a few millimeters, while the apple falling to the earth passes through a distance of 5 meters in the very first second. The observation of the mutual attraction of surrounding bodies is a task to which physicists have devoted much attention and on which they are still constantly engaged. Numerous observers have spent on this problem all their labor and ingenuity for years, and have used all the available resources of micro-mechanics. In this way we have at last arrived at a very accurate estimate of universal gravitation and are able to state with precision the force of attraction exerted on each other by two bodies measured in grams or kilograms. Now these are the observations which may be employed in estimating the mass of the earth. We know directly the force with which the earth attracts bodies on

its surface, we also know the size of the earth and therefore the distance between its various parts and the bodies on its surface; and thus the laboratory observations on the mutual attraction of bodies enable us to calculate the total mass of the earth. We find that the total mass is five and a half times greater than it would be if the entire space occupied by the earth were filled with water; in other words: The various kinds of substances contained in the earth are on an average five and a half times denser than water. This figure, $5\frac{1}{2}$, is the culmination of all the observations on gravitation of which I speak. But in this number, you will understand, the physicist also perceives the outcome of a sum total of human labor, by which one of the forces of nature dominating the world has been brought nearer to human perception.

The rocks on the earth's surface are only $2\frac{1}{2}$ to $3\frac{1}{2}$ times heavier than water; hence, since the earth is on an average $5\frac{1}{2}$ times heavier than water, it follows that at a certain depth the density must be greater than $5\frac{1}{2}$. It has been suggested that this greater density may simply be an effect of the pressure exerted by the overlying layers of the earth on the underlying. I have never been able to subscribe to that view, since everything that we know concerning the constitution of matter, and its construction out of the highly resistant atoms, indicates, it seems to me, that a notable compression by the pressure of the earth is not to be expected. Thus it seems to me that the greater density in the deeper depths of the earth's interior can only be explained by assuming that heavier substances, especially metals, predominate there. At any rate, you see that we are here in a state of uncertainty. We are compelled to ask, Are there not other means by which the distribution of mass in the body of the globe may be inferred? In point of fact, they may be found. First of all, there are the observations on the shape of the earth.

You know that the earth—assuming its surface to be represented by the surface of the sea, which we conceive as extending also through the continents—is not an exact sphere, but has been flattened at the poles, owing to the centrifugal force of its rotation. This flattening is of the greatest importance for general geophysics and for all estimates concerning the mutual position of points on the earth's surface. It must be taken into account in all land measurements, in all surveys intended to ascertain the geographic distribution of lands. Such geodetic observations form also the basis of the calculations by which we ascertain the size of the earth. The magnitude of the flattening also manifests itself in the distribution of gravitation on the earth's surface. That this may be the case you will readily understand, if you consider that it is gravitation that determines the shape of the surface of the sea. It has been found that gravitation becomes greater the farther we remove from the equator and approach the

poles. One kilogram at the pole exerts the same force as 1 kilogram 5 grams at the equator. A pendulum clock set correctly at the equator would gain 3½ minutes every day at the pole, by reason of increased gravitation, though the length of the pendulum remains the same. The observation of these variations in gravitation is also one of the methods by which we may infer the flattening of the earth. It would even seem as if this method were at present the best. This is all the more the case because an enormous number of observations have been made in the study of variations of gravitation on the globe, for the purpose of determining the flattening and for other geophysical purposes, some of which I will mention later on. On mountains, in valleys, in plains, in the interior of continents, on coasts, on islands, on the open sea, measurements of gravitation have been made. The Geophysical Institute on Hainberg possesses a special treasure in an apparatus for the measurement of gravitation, which some years ago was carried by the German South Polar Expedition on the ship named after our great mathematician, astronomer, and geophysicist, Gauss, of Göttingen, in order to make gravitation measurements in the South Polar Sea, so rarely visited by human beings. As the shape of the earth is influenced by the distribution of gravitation, it also shows itself in the effect exerted by the earth on the moon. By reason of the flattening of the earth, the moon revolves somewhat differently from what would be the case if the earth were a perfect sphere. Here is a third way of determining the flattening of the earth. It is practicable, too, for the movements of the moon must be determined with extreme care, on the one hand for scientific reasons, and on the other because the movement of the moon in the sky supplies an important means for determining geographic position, which is of importance, especially for the navigator. Now the final result of thousands of observations and of the extensive mathematical investigations to which I alluded culminates in the statement that the flattening of the earth amounts to about one two-hundred-and-ninety-eighth—that is to say, that the radius of the earth at the pole is about one two-hundred-and-ninety-eighth shorter than the radius at the equator. You will notice that, as in the case of the measurement of gravitation, the final result of an immense amount of labor is a simple numerical figure; but you will understand that to the investigator this one figure recalls the struggles, the toil, the success of a whole science.

I will mention that the figure one two-hundred-and-ninety-eighth is not yet quite accurately determined; it is possible that the value one two-hundred-and-ninety-seventh or even one differing still more may prove to be the true value.

Now, what significance has the flattening for our speculations on the interior of the earth? For an answer we must apply to the

mathematical theory of gravitation. It tells us, first of all, that the flattening would have to be one two-hundred-and-thirtieth if the masses in the earth were uniformly distributed, and one five-hundred-and-seventy-eighth if the main mass were located at the center. As the real flattening is one two-hundred-and-ninety-eighth, or very nearly that, it follows that the distribution of the mass in the interior of the earth lies between the two extremes; that is to say, the density increases toward the center, but at such a rate that a notable part of the mass is present in the outer layers. This, in fact, is the result at which we had already arrived. A further conclusion to be deduced from the figure one two-hundred-and-ninety-eighth is a certain statement concerning distribution, which can only be formulated in its full extent by means of mathematics, and which I am therefore unable to place before you. The situation becomes much more favorable, if I now make use of the suggestion, already referred to as a very natural one, that the earth consists of a metal core enveloped in a mantle of rock. As we know the thickness of the rocky mantle to a certain extent from direct observation, we are enabled, on the basis of the figure one two-hundred-and-ninety-eighth, for the flattening, to calculate the size of the metal core and its density. It is found that the rocky mantle on which we live must be 1,300 to 1,600 kilometers thick (800 to 1,000 miles), and that therefore the metallic core, so far as its diameter is concerned, occupies about four-fifths of the globe. It also appears that the density of the metal core must be a little more than eight times as great as that of water. The density of iron under the pressure conditions known to us at the earth's surface is a little less than eight. Thus we see that we obtain for the density of the metal core of the earth a figure corresponding to the density of iron when somewhat compressed or somewhat alloyed with heavier metals (for example nickel). We are thus led to the conjecture that the metal core consists in the main of iron. In support of this conjecture we are able to bring forward quite an array of additional arguments. In connection with volcanic eruptions, rocks rich in iron are often ejected from the depths of the earth. The meteorites which drop on the earth from planetary space consist partly of rock and partly of metal, iron being by far their predominant constituent. Analysis of the sun's light by means of the spectrum shows that iron vapors have a vast share in the composition of the sun. It thus appears that iron is very strongly represented in the structure of our solar system, and in particular that our earth is simply an iron ball coated with rock. It simply represents on a larger scale a meteorite which consists of a mixture of rock and iron.

Interesting as these conclusions are, we must not forget that they rest as yet on a very weak foundation. They would vanish at once, for example, if the increase of density toward the interior of the earth

were merely an effect of pressure and not of difference in material. It is exceedingly fortunate, therefore, that our conclusions receive new and very strong support from another and entirely different direction, that of earthquake investigation. But before I proceed to explain this, I must refer to two other phenomena of nature, whose data may be utilized in drawing conclusions concerning the condition of the interior of the earth.

I refer to the question of the plasticity of the earth under the influence of deforming forces. Aside from the phenomenon of earthquakes, there are two natural processes that bear on the question—(1) tides, (2) polar oscillations.

The tide, that "breathing of the sea," is to you a familiar phenomenon in its main features. Many of you have doubtless been eye witnesses of it on the shores of the North Sea. The causes of the tides are easily understood; they are to be sought in the attraction of sun and moon. Each of these heavenly bodies attracts the water of the sea more strongly on the side of the earth nearer to it than it does the earth's body as a whole, while on the opposite side of the earth it attracts the water of the sea more feebly than it does the body of the earth, which in this case is nearer to the attracting body. The stronger attraction on the near side, as may readily be seen, produces an upheaving of the water—that is to say, a flood tide; but there is also a flood tide on the off side of the earth, because, since the water there is more feebly attracted than the earth's body as a whole, it assumes, in the course of the earth's movement in space, a position relatively more distant from the attracting body than the earth, which means nothing else than that it rises in the form of a flood tide, relatively to the earth. Thus both the sun and the moon are each accompanied by two flood tides, one on the near side, the other on the off side of the earth; and in view of the revolution of the earth and the relative movements of the heavenly bodies, the result is that to the observer on the earth's surface sun and moon are each followed in their course around the earth by two flood tides. The moon is so much closer to the earth than the sun that despite its smaller mass the tides caused by it are more than twice as large as those caused by the sun. As a consequence, the sun tides do not present themselves as separate from the moon tides, but merely as modifications of them. At new moon and full moon the sun's tide reenforces the moon's tide, and we have the so-called "spring tides." At half moon the sun's tide is opposed to the moon tide, and then we have the "neap tides." At any rate, to the observer the tides seem always to follow the moon in its course through the heavens. Because of the daily revolutions of the earth around its axis and the moon's own motion about twenty-five hours pass before it has accomplished apparently one revolution around the earth, and thus, inas-

much as two flood tides are moving around the earth, the tide phenomena recur at intervals of about twelve and one-half hours.

I have tried to set forth to you the fundamental facts of the tide phenomenon, but I must add that in reality the process is exceedingly complicated. On the one hand, astronomic factors enter into the problem, for example, the fact that both the sun and the moon are now farther north and again farther south; on the other hand, the irregularities in the distribution of water and land on the earth lead to extensive modifications in the course of the tides which are difficult to estimate. How strong these influences are you may gather from the fact that the tides on the shores of the North Sea come from the Indian Ocean. South of America, Australia, and Africa there is a broad belt of open water; there the tide waves develop freely. Starting from the Pacific they run through the Indian Ocean, and as they enter thence into the Atlantic Ocean south of Africa, a part of each tide wave is deflected northward into the Atlantic Ocean. In the course of a little more than twelve hours these partial waves reach England and then pass around it on the south and north into the North Sea. The velocity becomes slower and slower with decreasing depth. After issuing from the Indian Ocean it takes the tide about two days to reach our German coasts.

Now, what does the tide teach us regarding the condition of the globe? If the earth were entirely plastic—that is to say, if the interior were in the main in the liquid or even the gaseous condition, as has been assumed from time to time by the imagination of some scientists—there could be no ebb or flood. The earth's body itself would in that case be deformed under the varying attraction of sun and moon, and the result would be that a relative movement of the sea such as is indicated by the rise and fall of the tide could not take place. Hence, the existence of tides proves that the earth acts in the main as a solid body.

Thus there can be no doubt that the earth possesses a certain power of resistance to changes of form. But what is the extent of this power? Combining observation and calculation, we can draw an inference on this point also. The ordinary half-daily tide, indeed, can not be used for that purpose, because, in regard to this, it would be too difficult to form a correct estimate of the influence of the irregularities in the distribution of land and water. But the half-monthly tide connected with the movement of the moon from north to south and back, in its revolution around the earth, may be utilized, for in this case, owing to the slowness of the process, the sea has time to follow the varying forces of attraction without disturbing current phenomena. This half-monthly tide, indeed, is very small, but in view of the extreme precision with which, in the interest of navigation, the changes of sea level are observed and used for calculation,

it is possible to disentangle it from the apparent chaos of oscillations. If thereupon we compare the size of the real flood with that which might be expected according to mathematical theory, with that which according to calculation should result from the moon's attraction, we find that the globe is certainly at least as rigid (riege) as steel. Let me explain the word "riege," which is somewhat unusual. You know that even steel is flexible; every knife blade, every steel pen proves it. The less yielding a material is in this sense, under the influence of the same force, the more rigid (riege) it is. Steel is one of the most rigid bodies that we know. Now, the behavior of the earth as regards the tides proves that in rigidity it is at least equal to steel. This remarkable result is confirmed and defined with greater precision by an examination of what are called "polar oscillations."

As you are aware, the "geographic latitude" of a place is measured by degrees of an angle. By this we mean the angle which the plumb line forms at the place in question with the axis of revolution of the earth. This latitude is of fundamental importance in all astronomic measurements, and hence it receives the most careful attention in all observatories. Now it was noticed that the observations did not always give exactly the same latitude. At first it was suspected that this arose from local disturbances of observations, against which the observer has to struggle constantly in all scientific researches. But when the thousands and tens of thousands of observations were systematically tested, it became apparent that the cause was to be sought not in local but in cosmic influences. It appeared probable, and it was afterwards demonstrated by observatories specially erected for the purpose, that the cause is to be sought in continual displacements of the axis of revolution of the earth. In other words, the earth does not turn steadily on the same axis, but changes its axis of revolution constantly within certain limits. Imagine that you are stationed at the place where the imaginary axis emerges from the globe; that is to say, at the "poles" of the earth in the astronomic sense, and you will have to conceive these "centers of revolution" as being located not at an invariable point of the earth's surface, but as shifting their positions. According to the observations thus far made, they migrate around certain definite mean positions, from which they depart at times as much as 10 meters.

What mean these migrations of the poles of revolution? That they can take place at all is not surprising to the physicist, for the earth is essentially a spinning top, and such "pole oscillations," that is to say, such displacements of the axis of revolution, may be observed in every top. Mathematical theory teaches that they must occur whenever the axis of revolution does not coincide accurately with the "axis of figure." It is safe to assume that the rotation of the earth does not take place precisely around the axis of figure, nor is this

surprising, for we do not know the early history of the earth which has brought it to its present condition. But the moment we examine the pole oscillations on the basis of existing observations more accurately, we find several remarkable facts. Theory teaches the following: If the earth were perfectly rigid, that is to say, if it were not yielding in the slightest degree, and if no disturbances intervened, the axis of revolution would have to move incessantly and with the same velocity around the axis of figure, so that the astronomical poles of the earth would constantly describe the same circles around the mean position. Astronomy is able to indicate in what time a revolution would be completed, namely, in three hundred and five days. But when we consult the observations we find a totally different course of the pole oscillations. There is indeed a circular movement of the poles in the true sense, but it takes place not in three hundred and five days, but in four hundred and twenty-five days. Moreover, the curves described change their width in an apparently irregular manner from revolution to revolution. These latter irregularities indicate that disturbing causes are constantly at work which continually displace the axis of revolution. It has been found that even the meteorologic processes in the atmosphere suffice to explain these displacements. Some geophysicists suggest that earthquakes may cooperate. Be this as it may, it is evident that the irregularities present no difficulty to the explanation, and thus we need not trouble ourselves about them. But what shall we say to the fact that the circular path of the poles is traversed not in three hundred and five but in four hundred and twenty-five days? Here we have arrived at the point which invests the phenomenon of pole oscillations with great significance for the question of the condition of the globe. In fact, from the difference between the observed time of revolution and the time ascertained by calculation under the assumption of a perfectly rigid globe, it may be inferred that the earth is not absolutely rigid but plastic. Part of this plasticity is to be accounted for by the movable, liquid body of the sea; but it can be shown that this accounts for only about one-fourth of the difference between three hundred and five and four hundred and twenty-five days. Hence the earth beneath our feet, which to our senses seems absolutely rigid, must to a certain degree be yielding. It is possible to calculate this degree of yielding, and we find that it is about half as great as if the globe possessed the rigidity of steel. In other words, the earth opposes to the deforming forces about twice the resistance that steel manifests under the conditions under which we observe it in our daily life. You see that the phenomenon of the pole oscillations carries us much further in our inquiry into the condition of the globe than does the phenomenon of the tides. From the observation of the tides we were merely able to infer that the earth is at least as rigid as

steel. We had no ground for assuming that it was not absolutely rigid. The pole oscillations, on the other hand, demonstrate that the earth is not absolutely, but only relatively, rigid, and they indicate the degree of rigidity.

Far greater yet is the degree of precision which our conclusions many attain along another line of research, to wit, that of earthquakes.

The awful phenomena of earthquakes, in which the firmest thing we know—the ground on which we walk—begins to shake, and in which often in a few moments all human work is reduced to ruins and thousands of human lives destroyed, have always powerfully attracted the attention of men. Fervid fancy was tireless in picturing ever new horrors. It was supposed that the tremors were due to the movements of fabulous monsters, or to the malign fury of demons, or to the anger of the deity. With the increase of civilization, natural science began to occupy itself with the phenomena of earthquakes. At the present day civilized nations have united in common systematic work. The Göttingen Geophysical Institute on the Hainberg represents one of the German seismologic stations. For some years the Göttingen Scientific Society has maintained a station for geophysical observations in the tropical belt of the Pacific, at Apia, on German Samoa, and one of its adjuncts is a seismologic station.

At first the observation of earthquakes was naturally confined to the direct investigation of the traces left by them. Soon, however, special instruments were employed in order to gain a more accurate idea of the nature and magnitude of the earthquake movements. As these instruments were improved, the scope within which tremors could be observed at a distance from their focus grew wider. Finally it appeared that instruments of sufficient delicacy are able to record the tremors produced by every large earthquake originating anywhere on the globe. Since that time—from about 1890 onward—earthquake investigation gained a mighty impulse; for the observer was henceforward no longer confined to local investigations, but enabled to trace the earthquake processes of the whole earth from any station, no matter where situated.

Science asks, What is the significance of earthquakes in the history of the development of the earth? What is the nature of the shocks that are propagated to a distance? What paths do they follow? What do they tell us regarding the condition of the globe? Anxious humanity will also demand an answer to the further question, How can we know what localities are endangered, what antecedent symptoms may be used as warnings, and what sort of structures must be erected in order to afford protection?

You see the tasks are numerous and involve profound interests of science and of human life. Thus we can understand the extraordinary

zeal with which earthquake investigations are conducted nowadays. I must resist the temptation to present to you a general picture of this activity and of its achievements, for my time is drawing to a close. For the purposes of our present theme, we are concerned only with one question, What do earthquake observations teach us concerning the condition of the globe?

Volcanic eruptions are accompanied by earthquakes; earthquakes also result from the collapse of subterranean caves, for example, those hollowed out by water. But both the "volcanic earthquakes" and the "collapse earthquakes" are only of subordinate importance for the globe. In the main, earthquakes occur when sudden displacements take place in the earth's crust, along fissures either of ancient origin or newly developed. The displacements thus formed on the surface, and the shocks by which they are accomplished, are the factors that produce the fatal effects. But all this I mention merely in passing. The essential point for our present purpose is that earth tremors starting from the focus of the quake pass through the body of the globe as elastic waves. To these earthquake waves we must now turn our attention.

The oscillations of the ground caused by these waves are recorded by the seismometers of the seismologic stations. It is found that the oscillations of great earthquakes are preceptible for hours. At the same time various kinds of oscillations may be distinctly observed, which pass through the globe at different rates of velocity. The swiftest are those waves in which, as in the case of sound waves in the air, the oscillations take place in the direction of the movement of propagation to and fro, the longitudinal waves, as they are called in science. Transverse waves, in which, as in the case of light, the oscillations take place at right angles to the direction of propagation, show only half the velocity of the longitudinal waves. Considerably slower even than the transverse waves are the rocking waves, resembling sea waves, inasmuch as they pass along the surface and do not reach a great depth. It is precisely the last-arriving surface waves that as a rule cause the greatest oscillations of the ground, far from the focus, and which accordingly become most prominent in the records of the instruments; they are on that account called "principal waves." In contradistinction to them, the longitudinal waves first arriving are called "first precursors" and the next-following transverse waves are called "second precursors."

As the principal waves are limited to the surface, they can give us no information on the condition of the deeper parts of the earth, and hence we are not now concerned with them. The case is different with the "precursors." Their behavior shows that their paths lie through the body of the globe. From the observations made at the surface we are, in fact, enabled by the aid of calculation to trace their

paths with accuracy through the depths of the earth. How is that possible? I must attempt to give you at least an approximate idea of it.

If the precursors remained at the surface of the earth, the velocity with which they are there propagated would have to remain the same at all distances from the focus. Now, this is not the case. On the contrary we note that the velocity of their propagation increases the farther we remove from the focus and the closer we approach to the opposite point. We are thus led to the conclusion that these waves must find paths of more rapid propagation in the depths of the earth. By studying the manner of their propagation along the surface it is possible, by means of mathematics, not only to calculate their paths in the interior of the earth but also to ascertain the velocity of their propagation along those paths. It is a beautiful illustration of the power of mathematics that all this can be done without any appeal to unsafe hypothetical assumptions. We are merely concerned with reliable deductions from the observations themselves. The more accurately we are able, by the aid of the seismologic stations, to record the rate of propagation of the waves on the surface of the earth in point of time, the more accurately are we able to trace the paths and the velocity of the earthquake waves in the interior of the earth. At this moment there are probably 100 seismologic stations in existence, with instruments which constantly record the earthquakes. Quite a number of these stations possess instruments so fine and so carefully watched that the arrival of earthquake waves can be recorded with precision to within one or two seconds. Thus even at this day, when we can look back over hardly more than ten years of more intense work, we possess a mass of records that we are able to use for reliable deductions. And what do we find? I hope that you will feel some astonishment when I announce the results, and to share with me to some degree the investigator's joy, when I address you as the representative of geophysics.

It is found that to a depth of about 1,500 kilometers the velocity both of the first and of the second precursors steadily increases, to become suddenly almost constant from that point onward. It is probable that there is a gradual increase in velocity even beyond that point; but this is so slight that existing observations do not as yet permit any definite conclusion regarding it. This statement is valid to a depth of about 3,000 kilometers, that is to say, about halfway between the surface and the center of the earth. Existing observations do not permit us to carry our inferences farther into the interior. But I think even this is a respectable achievement, and, moreover, we have every hope of farther advance and eventually reaching the center.

We will now turn to the point in which we are specially interested. While the behavior of the earth's strata changes at a uniform rate down to a depth of about 1,500 kilometers, a sudden jump occurs at that depth. What does this mean? Evidently we have to infer that at a depth of 1,500 kilometers there is a sudden change in the condition of the earth's strata. Recall now, if you please, what I said in the beginning of my address concerning the conclusions which we are authorized to draw concerning the masses in the interior. We found that in all probability the earth contains a metal core embedded in a rocky mantle some 1,300 to 1,600 kilometers thick. You will admit that the evidence furnished by earthquake study agrees with this conclusion in a remarkable manner. We are justified in assuming that the place of the jump in the propagation of earthquake waves is precisely the passage from the rock mantle to the metal core. Thus vanishes the uncertainty which affected our conclusions concerning the composition of the earth out of core and mantle, so long as we were able merely to appeal to observations on gravitation and on the flattening of the earth. With greatly strengthened confidence we may now affirm that the earth consists of a metal core enveloped in a rock mantle. Previously we were only able to estimate the thickness of the rock mantle in a crude way as approximately 1,300 to 1,600 kilometers. The earthquake phenomena now tell us that the thickness amounts to about 1,500 kilometers. The residuum of uncertainty can hardly exceed 100 kilometers. Similarly, our previous inference regarding the density of the metal core now attains increased certainty, and the conclusion that the material of the metal core is mainly iron gains a new support.

I have not yet given you any indication of the velocity of propagation of earthquake waves. I will now state that the first precursors traverse near the surface about 7 kilometers in a second, and in the metal core about 13 kilometers in a second. In the case of the second precursors the corresponding figures are about 4 kilometers at the surface and 7 kilometers in the metal core. The principal waves, which move along the surface of the earth, traverse about 3.4 kilometers in a second.

The mathematical theory of elasticity enables us to infer the elastic properties from the velocity of the elastic waves. Thus the earthquake observations of the present day also place it within our power to determine the elasticity of the earth's strata with accuracy down to half the distance from the center. We find that as we descend, the rigidity of steel, that is to say, its elastic resistance to changes of form, is exceeded after a few hundred kilometers. The metal core shows a rigidity four times as great as that of steel. All this agrees perfectly with what we learned concerning the rigidity of the earth as a whole, from the tides and from the oscillations of the

poles. We are also enabled to calculate the compressibility of the earth's strata by pressure. As a definite inference therefrom, we learn that the increase in density toward the earth's interior can not be explained by the pressure of the overlying strata. What I was at first able to present to you merely as a conjecture, namely, that the differences in density in the earth indicate differences in material, thus becomes a definite and precise outcome of observations.

But how are we to explain why the rigidity increases so rapidly toward the interior, and in the core is even four times as great as the rigidity of steel, seeing that we are to suppose the mantle to be composed of the known rocks, and the core mainly of iron? The answer is very simple: Evidently we have here the effect of the pressure of the earth's strata, which forces the molecules closer and closer together the farther we penetrate into the interior of the earth. As proved by calculation, the pressure at the surface of the metal core amounts already to half a million atmospheres and increases toward the center of the earth to about 3,000,000 atmospheres. Under such circumstances, it may readily be conceived that there must be an increase in rigidity. The fact that earthquake phenomena furnish information concerning the behavior of matter under such high pressure is of the greatest importance for physics, for by our human appliances in laboratories we are enabled to produce a pressure of at most a few thousand atmospheres.

You will probably expect me to say something regarding the temperature in the interior of the earth. I can not say much. That the temperature is very high is proved by the rapid rise observed wherever men have penetrated into the interior—in mines, in railway tunnels, in drill holes. It is also proved by the hot springs and, above all, by the volcanoes. Near the earth's surface, where we are able to make direct observations, we find an increase of temperature of about 2 to 4 degrees centigrade for every 100 meters. Considerations based on these observations suggest that in the far interior of the earth the temperature must surely attain some thousands of degrees centigrade. That the material of the earth nevertheless does not become liquid or even gaseous at such high temperatures, but is proved to be very rigid, must be attributed to the extreme pressure, which packs the molecules together and robs them of their mobility. Keeping this in mind while trying to ascertain the physical behavior of bodies with increase of temperature, we may infer that the temperature in the interior of the earth must certainly remain below 9,000 degrees; in all probability it does not even reach 4,000 degrees.

Let us look back over everything that has been discussed to-day. As the verdict of science, we learn that the earth has become, as it were, transparent to our view. In particular the earthquake waves

render to the geophysicist somewhat the same service that the Röntgen rays render to the physician who tries to examine the human body.

If we consider the feebleness of human means, natural science may well be proud of its achievements. But we should not forget also that the retrospect affords us no less motive for humility; for, as I tried to point out, success was only achieved by an immense expenditure of labor and pains. And yet I have reported to you only the advances, and have said nothing of the failures and mistakes, nothing of the labor that was spent in vain.

In fact, in this respect geophysics does not differ from the other branches of natural science—every forward step which man is able to make in the path of knowledge is dearly purchased. But this need not discourage us. So long as the joy of life fills the breast of man conquerors will be found ready, not as dreamers but with the will to do, placing their strength resolutely and joyously at the service of the investigation of nature.

I will add by way of supplement a few remarks additional to those made in the address.

(*a*) *The moon a drop of the earth's crust.*—To man, standing on the surface of the earth, the tide waves seem to run around the earth with the moon. But if we imagine an observer stationed in space he will have the impression that the earth revolves beneath the tide waves created and held in position by the attraction of the moon and sun. As the tidal currents involve friction of various kinds, it is evident that the earth must be checked in its revolution. The retardation is but slight; calculating from the present factors, we infer that it would merely add one second to the length of the day in about five hundred thousand years. However, looking back into the past, we find that many millions of years ago the earth revolved far more rapidly than it does now. The tidal friction has another consequence of importance for our inquiry: It causes the moon to move farther and farther away from the earth. To understand how this comes about we must note that the rotating earth drives the tide waves somewhat forward, in advance of the moon. As a consequence, the tide waves, by reciprocal gravitation, impart to the moon a constant forward impulse, and this acceleration, which means an increased force of revolution, drives the moon away from the earth.

If, with our minds filled with the ideas thus gained, we go back to remote ages, we arrive, by the aid of calculation on the basis of actual conditions, at a time when the earth performed one revolution in a few hours, while the moon revolved around it in immediate proximity, in the same space of time. This evidently leads us back to the time when the moon itself originated by detachment from the earth. The process must have been somewhat as follows: In the early ages the earth in its outer parts was liquid, or even gaseous. Contraction, due

to cooling, caused its motion to become more and more accelerated, till finally it reached a point where gravitation was no longer sufficient to maintain the ellipsoidal shape. As inferred by calculation, the subsequent detachment of a drop began thereupon to be preindicated by the development of a pear-shaped appearance. This pear-shaped body was constricted more and more, until the original single planet was divided into a main body, the earth, and a satellite, the moon. As the moon was thus formed of the outer parts of the original body, we infer that it consists of the same material that in the earth was arranged in the form of a rock mantle. The friction of the tides thereupon carried the moon farther and farther away from the earth, and diminished the rate of rotation of the earth. Thus the moon, which to-day describes its orbit at a great distance from the earth, is simply a drop detached from mother earth by the centrifugal force.

A very interesting question is that regarding the time that has elapsed since the moon was severed from the earth. Keeping in view the magnitude of the forces at work in the tide phenomenon, we can form at least an approximate judgment concerning it. We infer that it took place about ten thousand million years ago. By an "approximation" we must understand in this case that the time can hardly have been more than one hundred thousand million years, but very probably more than one thousand million years. Life on the earth can only have begun a good while after the separation of the moon, and yet we are forced to admit that life has lasted several thousand million years.

Compared with human life, a period of ten thousand million years appears enormous; and yet it is so small that even the moon can not have lost, during that period, any great fraction of the heat that it took away at its birth. Thus we have to infer that the moon, like the earth, is still intensely hot in its interior. As the pressure conditions in the interior of the moon's body must be similar to those existing in the rock mantle of the earth, we arrive at the conclusion that the physical conditions of matter in the rock mantle of the earth are not greatly different from those prevailing in the body of the moon. We saw that the material, too, must be the same. Thus we are presented with an opportunity to a certain degree to test the correctness of the views above developed; for if they are correct, the rock mantle of the earth and the body of the moon must have very nearly the same density. It was shown a while ago that, according to observations on earthquakes, the thickness of the rock mantle is to be estimated at 1,500 kilometers. If with this we combine the known data on the average density of the earth and the degree of its flattening, we may conclude that the material in the rock mantle is on an average 3.4 times denser than water. The average density of the moon, on the other hand, may be inferred from astronomic observations. And

what is it? Referred to water, 3.4. A better agreement than this could not be wished, and through it we gain a further and very important support for the whole series of our conclusions regarding the condition of the globe.

(*b*) *The earth's crust.*—Vast differences in elevation are found to exist on the surface of the earth. Some plateaus are situated 2,000 meters and more above sea level; the highest mountain tops rise to nearly 9,000 meters. The floor of the ocean lies on an average about 3,500 meters below sea level; the greatest depths of the sea attain about 9,000 meters. On an average, the land rises about 1,200 meters above the floor of the sea. In view of these facts it seems natural to infer that the elevations indicate accumulations of mass and the depressions deficiencies of mass, and in fact this was formerly supposed to be the case. But if this were really so, gravitation on the earth would have to be greater the higher the surface; but this is by no means the case. On the contrary, the measurements of gravitation have shown that while variations occur, indicating an excess or a deficiency of mass at various points, on the whole the mass of the earth is uniformly distributed over its surface. Thus the elevations and depressions of the earth's crust in a general way mean simply that in the former the crust is less dense, in the latter denser, and that for this reason it rises higher at the former points, less high at the latter.

These conclusions assume a special significance for the reason that, as shown by geologic investigation, rock strata many thousand meters thick have in the course of past ages, mainly through water circulation, been carried away from certain parts of the earth and deposited at other points. How is it possible that nevertheless the mass is to-day distributed with practical uniformity all over the earth? To explain this there is no other way than by assuming that the superficial accumulations of mass are compensated for by subterranean removal. Therefore the solid crust must have a soft substratum, on which it floats, as it were. Geologists have for this reason often been led to infer that the interior of the earth is liquid. We have seen that the earth as a whole, in the presence of the tidal forces, in the case of pole oscillations and of earthquake waves, behaves as a solid and that it is even remarkably unyielding in the matter of elasticity. Hence we can not conceive the interior of the earth as being liquid throughout, in the current meaning of the word. It is possible, however, that beneath the outer solid crust there exists at no very great depth a molten layer, so thin in proportion to the earth's body as not to cause any perceptible diminution of its rigidity. Volcanoes might then be regarded as vents connecting that layer with the surface. It might also be imagined that the liquid layer at the present day no longer extends beneath the entire

crust, but that it is interrupted by solidified portions and thus divided into provinces. Various phenomena of vulcanism would seem to agree better with that assumption. I will readily grant that such inferences may correspond to the reality; but yet it seems to me very remarkable that the observations on earthquakes furnish no indication of a liquid layer. While I must admit that the mass of existing observational material is as yet small, and that this fact may explain the circumstance just mentioned, yet while awaiting further developments, I am inclined to subscribe to the view that really liquid areas are found only in isolated parts of the earth's crust, and that on the whole the substratum of the crust is not "liquid," but merely "plastic." It is well known that many apparently solid bodies gradually yield even to very slight deforming forces, if these act long enough. A stick of sealing wax supported at both ends will bend, according to the temperature, in a few minutes, days, or years; pitch flows readily and quickly. Glass acts like sealing wax even under a slight rise of temperature, and the same has been proved to be the case with many minerals. There is reason to believe that by far the greater part of the substances surrounding us, perhaps all, are plastic, provided sufficient time is available for them to show it. Thus it seems possible that the earth's crust in the deeper, hot parts may indeed act as a solid toward the quickly passing earthquake waves, but as a plastic body toward the geologic forces acting through millions of years.

One more point has to be considered, which is of great importance, in many respects of decisive importance, for the shaping of the earth's crust and of the visible surface of the earth. A notable part of the rocks forming the earth's surface possesses the property, when subjected to high temperature and high pressure, of absorbing water and forming with it more liquid and less dense compounds. Thus we may well assume beneath the earth's surface a hot rock layer formed of these water-impregnated compounds; it is usually called the "magma layer." It probably represents the plastic factor which, by yielding to increased pressure, effects the equalization of mass in the earth's crust. During the gradual cooling of the earth the water is liberated from the magma. It has often been suggested, and I must confess that I am disposed to welcome the suggestion, that in this way the origin of the entire ocean may be explained, and that the hot springs show us at least some of the paths by which the water liberated from the depths of the earth by cooling and forced out by the pressure of the earth, is conveyed to the ocean.

One more remark. The plasticity of the earth's crust gives rise to a peculiar instability of the surface. If, in the case of differences of level, material is washed away from one part of the surface by water and deposited on another part, the earth's crust at the points of

denudation must rise in consequence of diminished pressure, while at the points of deposition it must sag by reason of the increased pressure. Hence, at the points of denudation hot, water-charged, and therefore less dense rock masses will rise from beneath, while at the points of deposition water-free, cold, and therefore denser strata will descend. Consequently, as a final result, the former higher parts of the earth become less dense, so that their surface, despite denudation, must be raised still higher, while the former deeper parts of the earth become denser and their surface therefore descends still lower than it was before. Thus denudation and deposition, instead of equalizing, accentuate differences of level. Mountains rise still higher, the sea bottom sinks still lower, and this continues until other factors make themselves felt. We have thus arrived at the exceedingly complex geologic processes which determine the formation and transformation of continents and seas, plains and mountains, and this reminds me that it is time to close, for the discussion of that theme would require a treatise by itself. I am all the more compelled to conclude at this point because even the indications that I gave exceed the limits of what is generally admitted in geology, and I shall therefore have to prove the correctness of my assertions elsewhere before the tribunal of science.

THE ANTARCTIC QUESTION—VOYAGES TO THE SOUTH POLE SINCE 1898.[a]

[With 1 plate.]

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Part I. History of the Expeditions.

Under the auspices of the French Academy of Sciences and of the Museum of Natural History of Paris, Dr. J. B. Charcot has in preparation a second expedition to the regions where from 1903 to 1905 he conducted the very successful cruise in the *Francais.*[b] Other expeditions, two English and one Scotch, are to explore the Ross and Weddell seas, and a Belgian circumpolar voyage has also been planned. Just as this second French enterprise is about to start in the endeavor to rob the southern ice fields of their secrets it seems fitting to briefly review some of the achievements of previous antarctic expeditions, and to give a general statement of the problems that it is hoped may soon be solved. The narratives of the explorers themselves and the numerous published observations shall be our guide, and as to those expeditions that are in preparation, or that have already started we shall refer to the instructions published by the Academy of Sciences for the guidance of Doctor Charcot.

SOUTH POLAR EXPLORATIONS SINCE 1898.

It was the successful voyage of the *Belgica* in 1898–'99 to Danco Land and the neighboring islands that opened up the present era of south polar discoveries. No other vessel before that under M. de Gerlache, equipped exclusively for scientific work, had wintered in the southern ice fields; no other explorer had been able to direct such exact observations and for so prolonged a period.

The limited scope of the present paper prevents a review of antarctic work prior to that of the *Belgica*, a story so well written by

[a] Translated by permission from Revue générale des Sciences pure et appliquées, Paris, 19th year, Nos. 13 and 14, July 15 and July 30, 1908.

[b] This paper was written April, 1908.

M. de Gerlache himself and by other earlier explorers.[a] Our aim will be to describe the characteristics common to the various expeditions toward the South Pole since 1898 and to note the special work of each.

Several of the cruises here described were munificently equipped, especially that of the *Discovery*, an English expedition, and the German expedition in the *Gauss*. The latter expedition was carefully prepared in the minutest detail in 1895 under the patronage of the Emperor and the great scientific societies of Germany, and was finally endowed with an appropriation of more than 1,100,000 marks ($275,000). Several of the vessels engaged in south polar exploration even when poorly equipped have achieved good results and lead to a hope for great success from others more generously supported. The *Belgica*, for instance, was a small vessel of 244 tons, and M. de Gerlache met all the expenses with 345,000 francs ($69,000). Doctor Charcot had at his disposal for the *Français* only 450,000 francs ($90,000), furnished by himself or collected after great efforts and haste through gifts and subscriptions, without assistance from the Government; and it can be truly said, according to the explorer himself, that he could have completed the task attempted had he had greater resources, and perhaps have taken better care of his scientific instruments and other equipment. Such an avowal teaches at least a lesson, referring, as it does, to an expedition that toiled so hard for the sake of science and for the fame of France. Nevertheless, all the expeditions have imitated each other in the care taken in recruiting the personnel, especially the staffs of specialists, some of them distinguished men. They have been baffled neither by difficulties nor dangers in recording observations which were extended as long as practicable with great accuracy. All the expeditions, without exception, have wintered once or twice in the ice fields. Finally, thanks to the generous supports of the governments and of the scientific societies, the results of their work have been published.

Regarding the difficulties in making scientific observations, which in some respects are even greater than in the arctic region, we shall call attention to only a few. Danger to navigation is always present in those rough and foggy seas, ever covered with floating ice. The great extent of the compact ice fields and the uneven range of icy coasts prevents near approach to the mainland and causes constant movement of the great fields of ice, often making it impossible to identify localities already known. All this creates a thousand

[a] See de Gerlache: Note sur les expéditions qui ont précédé celle de la *Belgica*. Bull. Soc. roy. belge de Géogr., 1900, pp. 365–531. De Gerlache, Doctor Charcot: Introductions de leurs récits de voyage, cited below. Pariset (E.): Vers la terre polaire australe. Mém. Acad. Sci. et B. Lettres de Lyon. 1905, pp. 247–374. And chiefly the classic book by G. Murray: Antarctic Manual, London, 1901.

dangers and delays to foot or sledge journeys, and finally the physiological effects of polar anæmia, which have been kept secret by certain travelers, may cause severe mental disturbances and result in fatal consequences. These conditions show how much we should be indebted to these intrepid explorers.

West antarctic explorations.

It was under the conditions enumerated that M. de Gerlache in 1898 undertook to explore, in the *Belgica*, the entire group of islands and lands south of Cape Horn, on the side of the South Shetlands, previously visited by Bellingshausen, Dumont d'Urville, and Dallmann. The explorer discovered the strait that bears his name, between Danco Land and the archipelago then called Dirck-Gherritz. He surveyed both shores and added many photographs to his survey, which was the first detailed one made in the south polar regions. After this the *Belgica* reached the southwest of Alexander I Land, pushed through the ice pack, and drifted from February 28, 1898, to March 13, 1899. On May 31, 1898, the vessel reached the limit of this drift in latitude 70° 40′ S. Such full scientific observations were obtained that they have aroused great interest in that region.[a]

In 1902 and 1903 M. Otto Nordenskjöld, in the *Antarctic*, extended these discoveries by exploring to the east and northeast of Graham Land, and located a perfect and separate group of polar lands, for which he proposed the name West Antarctide. He surveyed in detail the south shore of Bransfield Strait, into which the waters from Gerlache Strait flow through the Orleans Canal, and also surveyed the east coast of Louis Philippe Land, of King Oscar Land, and the adjacent islands (Joinville, Ross, etc.). The head of the expedition remained at Snow Hill (Seymour Isle), latitude 64° 22′ S., from February, 1902, to November 8, 1903, and was rejoined during the second winter by a party left at Bay of Hope (Gunnar Andersson), and a little later by the remainder of the *Antarctic* crew, who had left their ship, wrecked by the ice, to take refuge on Paulet Island. After twenty-

[a] Bulletin de la Société royale belge de Géographie for 1900 containing the accounts given by several members of the expedition since their return. See, especially, Arctowski: Géographie physique de la région visitée par l'expedition (pp. 93–175). See also E. Racovitsa: Résultats généraux de l'Expédition antarctique belge. La Géogr., 1900, pp. 81–92. The most important detailed descriptions of the voyage are the following: Dr. Fr. A. Cook: Through the first antarctic night. London, 1900. 8°. De Gerlache: Quinze mois dans l'Antarctique. Brussels, 1902. 8°.

The publication of the scientific results was begun at Antwerp in 1901, in quarto volumes, under the title "Expédition antarctique belge, résultats du voyage du S. y. *Belgica* en 1897–1899. Scientific reports: See Arctowski: Die Antarktishe Eisverhæltnisse. Pet. Mitth., Ergh. 144. 1903.

two months on the ice pack the expedition, relieved by the Argentine ship *Uruguay*, brought the results of observations taken at three different places, and completed by the journeys made by its chief over the ice pack at King Oscar Land.[a] But part of the collection was lost with the *Antarctic*.

M. Otto Nordenskjöld was still at Buenos Aires when the *Français* arrived with Doctor Charcot. As soon as he decided upon the expedition, with the support of the Academy of Sciences and of the Museum, M. Charcot had his ship built and hastily equipped, in order that France might share in discoveries in West Antarctica. The devotion and the spirit of endurance that marked the entire expedition during a stay of a year in the midst of the ice, bore full fruit. Two cruises permitted a survey of the Palmer Archipelago on the Pacific side, the exploration of the south part of de Gerlache Strait, and the resetting of survey marks on Biscoe Archipelago, as also on Loubet Land. The winter of 1904 was spent at Port Charcot (Wandel Island) and gave opportunity for continuous, accurate, and varied observations, completed during sojourns at Port Lockroy (Wiencke Island).[b] Figure 1 indicates the geographical importance of this work, even when compared with the work of the *Belgica* and *Antarctic*.[b]

Exploration of the ice fields to the south of the Atlantic and Indian oceans.

While it was thus established that south of Cape Horn there existed a land remarkably symmetrical with the extremity of South America,

[a] Otto Nordenskjöld: Au pôle antarctique. Translated by Ch. Rabot. Paris, 1904. 8°.

Otto Nordenskjöld et Gunnar Andersson: The Swedish Antarctic expedition. Geogr. Journ., 1904, pp. 207–220.

O. Nordenskjöld: Résultats scientifiques de l'expédition antarctique suédoise. La Géogr., 1904. Vol. II, pp. 351–362. Ibid., Note sur la glaciation antarctique. La Géogr., 1904. Vol. I, p. 5.

Seven volumes on the scientific results are announced; the publication of those referring to the natural history began in 1907. See several memoirs published in the Bull. de l'Inst. géol. de l'Univ. d'Upsal. and reviewed in the excellent bibliography in Ann. de Géogr.; O. Nordenskjöld: Recherches sur l'Antarctide de l'Ouest; Gunnar Andersson: Sur la géologie de la Terre de Graham.

[b] Doctor Charcot: Le "Français" au pôle Sud, Paris, 1906. 8°.

The volumes on scientific results are in preparation, to be issued at the Government's expense and under the direction of a commission chosen by the Academy of Sciences and by the Museum. A résumé of the observations may be found in the appendix at the end of the above-cited volume. See especially the note on meteorological observations by J. J. Rey (pp. 349–399); description of animal and vegetable life by J. Turquet (pp. 415–444); study of geology and of glaciology by E. Gourdon (pp. 444–460). Doctor Charcot has besides written about the scientific works of the expedition in La Géogr., 1906, pp. 245–260.

German and Scotch explorers undertook the study of the ice banks lying farther to the east already approached or entered by Cook, Bellingshausen, Weddell, J. Ross, and by the *Challenger* (1874). Regarding the large expanse extending as far as to the south of Australia, toward the scene of Dumont d'Urville's and Wilkes's cruises, the charts then indicated only approximately the location of the ice-pack front and of lands imperfectly seen or supposed to exist.

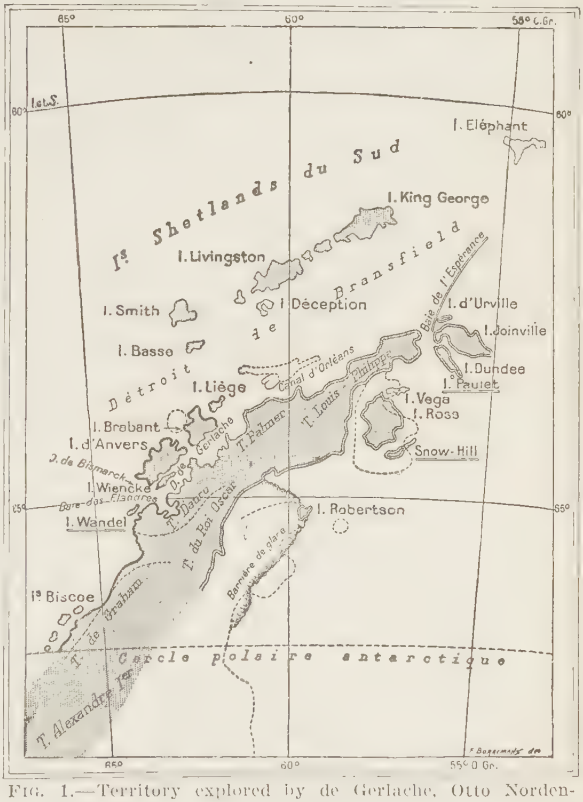

FIG. 1.—Territory explored by de Gerlache, Otto Nordenskjöld, and Charcot.

—— Surveys of the *Belgica*.
..... Hypothetical lines based on observations of the *Belgica*.
═══ Surveys of the Nordenskjöld expedition in the *Antarctic*.
▬▬ Surveys of the *Français*.
Double underline indicates a wintering station.

The German expedition in the *Gauss*, headed by M. von Drygalski, and which was exploring at the same time as the *Antarctic* (1902–3), was enabled, by wintering to the south-southeast of Kerguelen in latitude 66° 2′ S., to make a careful study not only of the ice bank, but also of the various formations of coast glaciers that bind it to the inland ice. Several perilous journeys permitted approach to the continental glacier to survey and make photographs of the volcanic cone of Mount Gauss, situated on its border and perhaps a part of the polar continent itself. The scientific instruments of the vessel, carefully kept and handled by expert specialists, made possible most accurate observations in physiography and natural history. The expedition was also provided with a balloon, which was utilized on several occasions.[a]

[a] Von Drygalski has issued a detailed description of the *Gauss* expedition: Zum Kontinent des eisigen Südens, Berlin, 1904. 8°. See also, Bericht über

It was farther west, toward the Weddell Sea, that Bruce's Scotch expedition in the *Scotia* directed its researches. The two campaigns of 1903 and 1904, signalized by journeys over the ice pack, gave opportunity to reconnoiter an ice cliff 30 or 40 meters high for a distance of 150 miles and which probably has a land base (Coats Land).[a]

Exploration in the vicinity of Victoria Land.

To the south of New Zealand, in the latitude where J. Ross in 1842, after the discovery of Mount Erebus, met the great ice barrier that bears his name, two scientific expeditions have established the contour of a part of the polar lands. The ship *Southern Cross*, which started at the same time as the *Belgica*, with M. Borchgrevink, sojourned in the polar zone from February 17, 1899, to January 28, 1900. This expedition began a detailed survey of the lands south of Balleny Islands; first, the northwest extremity of Victoria Land, where a meteorological station was erected on Cape Adare, and then at Coulman and at Erebus islands. A cruise toward the southeast along Ross's great barrier, and journeys over the ice pack as far as latitude 78° 50′ S., beyond the extreme point reached in the past, have helped to establish the nature of these formations between Mount Erebus and Edward VII Land. The very fine collections of natural history, the photographs of the coasts or valleys discovered and of the littoral moraines brought back by the *Southern Cross* constitute results of great scientific value.[b]

But the most successful and remarkable of all the Antarctic expeditions was that of the *Discovery* (1902–1904), superbly equipped as it was for the task. The reconnoitering and surveying of the coast of Victoria Land and the neighboring islands from Cape Adare and

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Verlauf und Ergebnisse der deutschen Südpolar Expedition, Zeitschr. für Erdk., Berlin, 1904, pp. 14–41.

The detailed scientific reports are published in illustrated quarto pamphlets. They have been reviewed in the following publications: Von Drygalski: Die deutsche Südpolar Expedition. Bericht über die wissenschaftlichen Arbeiten, Berlin, 1903. 8°. The Verhandlungen of the Fifteenth Geological Congress at Danzig (June, 1907) contains seven reports of the members of the expedition intermediate between the description of the voyage and the scientific results. Finally, Doctor Philippi, of the expedition, who had devoted himself and his recognized ability to the study of climate and glaciology, has issued, in the Zeitschr. der Gletscherkunde (July 1, 1907), a remarkable memoir entitled: "Ueber die Landeisbeobachtungen der letzten fünf Südpolar Expeditionen."

[a] W. S. Bruce, Rob. C. Mossman, etc.: First Antarctic voyage of the *Scotia*. Scottish Geogr. Mag., 1904, pp. 57–66, 113–133. For the second cruise, see ibid., 1905, pp. 23–37, 401–440.

[b] Borchgrevink: First on the Antarctic Continent. London, 1901. 8°. This description was reviewed in Geogr. Journ., 1901, p. 478. Another description is that issued by Bernacchi: To the South Polar Regions. London, 1901. 8°.

Mount Sabine to beyond latitude 80° S. (McMurdo Strait); the study of the regions discovered and of the littoral (Mount Melbourne, Mount Discovery, etc.); a fearless sledge journey for 300 kilometers over the interior of Victoria Land, a feat unique in austral regions; the wintering at latitude 78° S.; the point extended by Captain Scott, corresponding with longitude 160°, Paris meridian, as far as latitude 82° 17′ S. (south polar record); the study of Ross's great barrier and its connections with the adjoining lands; and, finally, an exceptional number of observations—such are some of the most important achievements that give an idea of the importance of this expedition. Scott, as also did Von Drygalski, added balloon observations to direct observations. He likewise studied, either going or returning, the southern ocean north of the Antarctic Circle, in the latitudes reached by Dumont d'Urville (Adelie Land) and by Wilkes, and expressed a negative opinion as to the existence of Wilkes's Land which no one will deem unjustifiable.[a]

WEST ANTARCTIC LANDS AND LITTORAL.

Several attempts have been made in France and abroad to bring together a general account of the results obtained by antarctic expeditions[b] or to discuss one or more of the important questions that have arisen,[c] but the best general descriptions are rather old, and the authors were not enabled to profit by all the narratives that have recently appeared.

It is with respect to all the lands south of America—that is, to use the name suggested by O. Nordenskjöld, West Antarctide—that the *Belgica*, the *Antarctic*, and the *Français* expeditions have brought together the greatest amount of accurate information. We can now draw the physical geographical contours of this region, not only by following the narratives of the voyages, the scientific reports, the photographs, but also by using the surveys or charts made on the spot, principally those by the staff of the *Antarctic* (Andersson: Carte géographique de la Terre de Graham à 1/5,000,000 et à 1/200,000) and by the members of the *Français* expedition (levés de l'archipel de Palmer à 1/100,000, de l'île Wandel à 1/200,000, etc.).

[a] He declares that Wilkes's Land is an illusion. Scott: The Voyage of the *Discovery*. London, 1905, 2 vols. Translated and published in French, 1908. The scientific reports are in course of publication. A summary of results has been published by several members of the expedition in the Geogr. Journ., 1905, pp. 353–405. Captain Scott's account contains two appendixes on the geologic observations and austral fauna.

[b] Zimmermann: Terres, climat et glaces antarctiques. Ann. de Géogr., 1902, p. 385.

[c] Supan: Das antarktische Klima., Pet. Mit., 1901, p. 128. Ch. Rabot: La glaciation antarctique, d'après les récentes explorations. La Géogr., 1907, p. 385.

An impression of repulsion has been felt by all at first sight of these lands. The phrases "fierce grandeur" or "wild solitude" are used often at the beginning of the narratives of the voyages. Photographs of the region justify such feelings, showing, as they do, the great ice-bound shores, with few small islands, the sharp mountainous heights, and the littoral ridges and black cliffs, their fronts hooded always with heavy mists where piedmont glaciers hold the place of shores.

The whole region forms a system remarkably symmetrical with the southern Andes, having the same outward appearance. Nearly all the principal altitudes are toward the Pacific. The mountain chain is broken into a multitude of islands. According to the name given by the geologist of the *Belgica*, it is an Antarctic Andes.

The scientific classification of the specimens of rocks collected by the explorers gives an idea of the general structure of this group of lands. The base, appearing in several places along the west littoral (Graham Land), is of primitive rocks, perhaps extending over wide areas buried beneath the covering of ice. The majority of the abrupt peaks along the coast, from Louis Philippe Land to Graham Land, and the high rocks of the islands of Gerlache Strait and of the Palmer Archipelago, relate back to ancient volcanic disturbances. In this class are the geological formations of Danco Land, between Wilhelmina and Flanders bays (granites, serpentines, and porphyries), and those of the Wiencke and Wandel islands (diorites, gabbros).[a] The high cones of Graham Land, such as the summit of Mount Matin (2,000 meters?), those of the Antwerp Island, where Mount Français rises 2,689 meters, and the peaks of Biscoe Islands are, perhaps, recently extinct volcanoes. The geologist of the *Français*, M. Gourdon, found as positive evidence in this connection only a ledge of trachytic andesite 200 meters high on Wiencke Island; but he gathered specimens of basalt from the débris of glacial moraines or from transported rocks in such quantities and at such an altitude that they could not have come from a very far-distant source.[b]

However, the existence of recent volcanic disturbances, though not active, on the southeast side of the Antarctic Andes is not to be doubted since O. Nordenskjöld's and Andersson's observations. Mount Haddington (2,150 meters), on Ross Island, and the cone of Paulet Island, are volcanoes of the same geologic period as the Andes. Basalts and basaltic tufas, cut by hard veins, cover in thick layers the sedimentary soil toward King Oscar Land.[c] The craters may form two series; one on Louis Philippe Land and Joinville Island, and the

[a] De Gerlache: Fifteen months, etc., p. 151. Doctor Charcot: Le *Français* au pôle Sud, pp. 41, etc., 445 (Gourdon).

[b] Doctor Charcot: Op. cit., p. 448.

[c] O. Nordenskjöld: Au pôle antarctique, p. 316, etc. Ibid.: La Géogr., 1904, Vol. II, p. 354.

other on Ross Island, parallel to the volcanoes of the South Shetlands, where Mount Bridgman is active.

Before the return of the Swedish expedition, the presence of sedimentary rocks in West Antarctic was only suspected.[a] The only support for this suspicion was a few schist fragments detached by Arctowski from the side of a hill in Wilhelmina Bay (Danco Land).[b] The discoveries by O. Nordenskjöld and his companions on the southeast of Palmer Land disclosed there the superposition one on the other of several geological beds, the highest being most likely of the Tertiary period. At l'Esperance Bay, Andersson and Duse obtained specimens of schist, in place, associated with a Jurassic fauna. On Ross and Seymour islands, under the volcanic basalts and tufas there are vast layers of fossil-bearing sandstone, containing in their lowest portion ammonites, and throughout the remains of northern plants, Sequoias and Araucarias, Cycads, Filices, together with remnants of vertebrate animals dating from the middle or upper Cretaceous. Finally, on Seymour and Snow Hill islands, superposed on the preceding layers and corresponding with them, have appeared deposits of soft sandstone, over which the snow does not remain, and which contain bones of a variety of great swimming bird or penguin of the Tertiary age.[c] The Quaternary formations have not been found outside of the coast moraines.

Thus we have a clear conception of the net conclusions which Nordenskjöld and Arctowski have formulated. The high chain of sharp peaks and the general southwest to northeast curvature which all the neighboring islands have is similar to that of the Andes and perfectly homologous with them. According to M. Lacroix, who has studied the specimens, this chain of peaks should be included in the American petrographic province. As in Patagonia, so in King Oscar Land, a plateau here covered with ice extends from this range to the eastward. It might have been said that these lands were still joined in comparatively recent times had not the soundings taken by the *Belgica*, between the Falklands and South Georgia, revealed depths of 1,985 fathoms toward latitude 53° S., which according to Dr. Fr. A. Cook do not extend elsewhere. In the instructions prepared for Doctor Charcot's next voyage, M. Gaudry does not, however, hesitate to state that "paleontological history is incomprehensible if Patagonia, Australia, and even Madagascar are not parts of the Antarctic continent." The only difference of structure between the antarctic lands and the southern part of South America is due to the absence, in the former, of the Quaternary beds on the east as

[a] Zimmerman: Ann. de Géogr., 1902, p. 385.

[b] De Gerlache: Op. cit., p. 127.

[c] O. Nordenskjöld: Op. cit., pp. 123, 130, 229.

represented in the "pampas" of the latter; but Arctowski explains this by the sinking of Graham Land, which would, in fact, account for the direction of the coast line in recent times, so deeply penetrated by the sea.[a]

POLAR LANDS SOUTH OF THE INDIAN OCEAN.

South of the Indian Ocean and as far as the Tasmanian meridian the charts of the latter part of the last century show a series of lands parallel to the Polar Circle and protected by a thick barrier of ice. Cook, Bellingshausen, Biscoe, Dumont d'Urville, and especially Wilkes (1839-40) have described this littoral which bars access to the antarctic continent, concealed, as it is, under its continental glacier and almost constantly hidden by the fogs, as a ledge low formed, regular, and blunt, and consequently of ancient origin. Until further observations have been made, it is best to be very cautious in determining the exact outline of the lands referred to, but their existence seems no longer to be doubted. That land is there is evidenced by the alignments of the ice banks; by the gradual shallowing of the sea as the barrier is approached, verified by the *Challenger*, by the *Gauss*[b] expedition, and by the soundings of the *Discovery* off Wilkes Land; and finally by land débris found in the icebergs and the samples of rocks dragged from the bottom. No doubt Von Drygalski found no traces of Termination Land, but the relocation of former marks in this region is very difficult, chiefly on account of change in position of the ice banks.

The position of Adelie Land, reached by Dumont d'Urville and later by Wilkes, under the very Polar Circle, longitude 140° E. of Paris, was generally acknowledged as fixed. The polar continent has since been reached, photographed, surveyed on one side, and its rocks classified. During their wintering in 1903 on the ice fields southeast of Kerguelen, the *Gauss* explorers were twice able to reach, in latitude 67° 20′ S., a rocky summit partly free from ice and marked with moraines of various ages. Mount Gauss, according to Doctor Philippi, rising to nearly 350 meters, is situated near the very border of the continental glacier which forms steep banks above the ice fields of the coast. At a distance the profile of Mount Gauss resembles a flat cone, recalling certain granitic summits of central France. Geological study made on the spot has shown that it is composed of recent volcanic rocks; on the summit are

[a] Arctowski: Géogr. Journ., 1901, pp. 150, 353; 1902, p. 405. Ibid., Bull. Soc. roy. belge de Géogr., 1900, p. 132. O. Nordenskjöld: La Géogr., 1904, Vol. II, pp. 354, 359.

[b] Von Drygalski: Zum Kontinent des eisigen Südens, p. 238.

lavas (leucitic basalts) with gneiss and granite blocks transformed by fusion. Débris of a like origin has been gathered in the neighboring moraines as also in the continental glacier and ice pack in the sea. A very significant illustration from Von Drygalski's account of the region shows one of the terminal cliffs of the mountain, formed of recent lava, finely perforated, its structure recalling the Volvic stone. During the second journey a sandstone block was studied. From the summit of the cone on which the ascension was made, and also from the balloon, the surface of the continental glacier toward the south looked like a narrow plateau with great regular crevasses in the ice, and mountain profiles were noted, lost in the far east.[a] Von Drygalski does not hesitate to believe that the "south polar continent" is there.[b]

VICTORIA LAND AND NEIGHBORING ISLANDS.

For a general review of lands south of New Zealand, the description given by J. Ross (1840–41) referring to the high insular volcanoes of Mount Erebus (3,769 meters) and Mount Terror furnish considerable information. The discoveries made by the *Southern Cross* and by Captain Scott's daring exploration have helped in tracing a chart of the littoral bordered by islands, stretching toward the pole as far as parallel 82° in the vicinity of meridian 160° E. of Paris.

The photographs brought back by Borchgrevink of the coasts and the valleys discovered on Victoria Land (Cape Adare, etc.) and of Coulman and Erebus islands, according to the chief of the expedition, indicated at once the rough character of the edge of this region, entirely volcanic on its surface. But he established the fact that the eruptive forms are caused by a sinking of schists which, according to his description, would extend from Wilkes Land to Erebus Island. Samples of these rocks, not located, were considered as practically identical with the paleozoic soils of Victoria State, from which developed the theory, rather advanced, of an extension of the Australian Plateau to Wilkes Land and of a connection between the volcanic range of Victoria Land and New Zealand.

The expedition in the *Discovery* established the contour of the littoral of Victoria Land and of the neighboring islands, and studied all the tracts discovered, the shore cliffs, glacial valleys, fjords and moraines, and mountain summits. The expedition disclosed the existence of a chain of coast volcanoes staked out from Cape Adare, by Mount Sabine, Mount Melbourne (2,400 meters), Mount Discovery (3,050 meters), and Mount Markham (lat. 82° 55′ S.). The numerous excellent photographs accompanying Captain Scott's description show

[a] Von Drygalski: Op. cit., pp. 271, 274, 302, 304.

[b] Ibid.: Pp. 3, 4, 330.

clearly the more or less dismantled conical form of these summits.[a] But the most interesting of all of the *Discovery's* findings is the sandstone with Miocene fossils, proved to exist in several of the glacial valleys of Victoria Land. Their strata, filled with basalts, are strictly horizontal and thick, no doubt in some places several hundred meters.[b] This observation would establish the period of the greater volcanic convulsions in the region, as also the sinking of Erebus Sea; both seem to be contemporaneous with the rising of the West Antarctica summits, and the chart also shows that both ranges seem to stretch one beyond the other across the icy solitude of the pole.

Without attempting to force a conclusion, one of the possible hypotheses concerning the contour of polar lands between Pierre I Island and Edward VII Land would be that of a great crescent corresponding to that portion of the polar ice where no vessel has yet approached save that of Bellingshausen in 1821.

Part II. Scientific Results of the Expeditions.

THE AUSTRAL SEA.

The complete scientific results of the voyage of the *Discovery* not having yet been published, it is concerning that part of the southern sea near West Antarctide that we have the latest information, and although the observers may have turned their attention in other directions, yet there are certain important conclusions that indicate a course for future expeditions.

At the close of the last century the charts showed the depths of the South Pacific toward latitude 60° S. and longitude 76° W. of Paris, to the southwest of Cape Horn. The charts indicated also a submerged plateau nearly 2,000 meters deep, on which rest the small archipelagoes between Antarctica and the Falkland Islands. The soundings of the *Belgica* and those of the *Scotia* in the South Atlantic and in Weddell Sea have established this fact. M. de Gerlache had proved that in Drake Strait, between the Falklands and South Georgia there is a depth of 4,040 meters in latitude 55° 51′ S.[c] Bruce's repeated observations (75 soundings) have established on this side the southern limit of the South Atlantic threshold, upon which rest the Falkland Islands, in about latitude 55° S. With a depth of from 3,000 to 4,000 meters, it drops into a submarine valley in latitude 60° S. more than 5,000 meters deep, extending from west to east from the Sandwich Group toward Kerguelen. The maximum sounding taken in Weddell Sea at latitude 70° 21′ S. was 4,650 meters.[d]

[a] Scott: The voyage of the *Discovery*, Vol. II, p. 152, etc.

[b] Ibid.: P. 140.

[c] De Gerlache: Op. cit., p. 104.

[d] Compare the soundings made by the *Gauss* southwest of Kerguelen as the ship was entering the ice (lat. 65° S.), showing a depth of 3,165 meters.

This depression would come near the Kemp and Enderby Lands; but, near the front of the glacier, a rise of the bottom proves the existence of a continental plateau. To the southwest of Graham Land, at the edge of the coast plateau, where the *Belgica* drifted, on the contrary, the depths appear to be less. In latitude 71° S. along Alexander I Land, the depth is about 2,700 meters.[a] To multiply the soundings during the coming expeditions all along Antarctica would add to our present vague knowledge in regard to the relationship in structure between this land and the Andes.

A further study of the sea currents with special reference to their movements and their fauna is desired, for up to the present time there have been only general observations or local data of temporary value. The surface temperature stands at about zero nearly the whole year. That of the bottom is remarkably low and increases as the ice is approached. From —0.3° in the Atlantic-Indian Valley of the *Scotia*, it reached a minimum of —0.6° in Gerlache Strait at a depth of 3,690 meters; and the Nordenskjöld expedition at a depth of 1,450 meters in Bransfield Strait found a temperature of —1.65°, the lowest then recorded.[b] Since then the *Southern Cross* publications record —2.3° as the mean temperature of the sea water under the Ross Barrier. These very cold bodies of water are peculiar to very great depths. The observers on the *Gauss* found between the cold strata at the surface and at the bottom the presence of a stratum of water of nearly +1°, salter than the surface and less dense than the bottom, due probably to currents from the distant Temperate Zone. Drake Strait, where Nordenskjöld observed not less than +1.9° at 1,400 meters, and the South Atlantic, where the *Scotia* met temperatures of from +0.1° to +0.5°, would mark on the west coast of Antarctica the northern limit of the polar bottom waters. As for the salty condition, the *Belgica* expedition found it to slightly diminish toward the south, due to the melting ice. Annual variations are slight, the maximum being during the winter, as would be expected.

MM. Arctowski of the *Belgica* and Matha of the *Français* made repeated observations regarding the density of the sea water, which are beyond the scope of this paper. Matha also studied the tides. From a maximum height of 2 meters, they have shown at Port Charcot a daily flood tide to be compared to that of Indo-China (only one flood tide each twenty-four hours, or two irregular ones).

ANTARCTIC CLIMATE.

Climatic conditions in the Antarctic regions have received the special attention of explorers. Observations have been numerous,

[a] De Gerlache: Op. cit., p. 162.

[b] O. Nordenskjöld: Op. cit., p. 191.

and have been sufficiently prolonged and accurate enough to establish the present general characteristics of the south polar climate. These results have already furnished interesting comparisons with what we know of the boreal region. We would especially seek now an explanation of the glacial phenomena so peculiar to the Antarctic and information concerning the organic life, which is altogether precarious or remarkably specialized.

Previous to 1898 the most southerly meteorological stations in the world, those at Ushuaia and on the States Isles (lat. 54° 23′ S.), had furnished reports only concerning the Cape Horn region. The observations made by the latest Antarctic expeditions, the most extended being the series of a year, by the *Antarctic* at South Georgia, have greatly increased this data. Even with respect to the ice-covered region our knowledge has been limited to isolated statements, which it was difficult to consider collectively with advantage. It may be said, however, that studies made by the last expeditions have enriched the geography of the region with a complete new chapter.[a]

Barometric observations have, first of all, demolished the hypothesis according to which, besides a zone of disturbances varying from latitude 60° to latitude 70° S., the prevailing rule in the Antarctic would be turbulent winds from the west, verging toward a permanent austral cyclone. The existence of these winds, due to the extension of the great currents of terrestrial rotation from west to east, south of the temperate austral zone, had been generally acknowledged, but this supposition can not be reconciled with that of an austral icy pole. The observations have, on the contrary, shown that the pressure, although very low as an average, does not regularly diminish toward the south, and differs little from the average of 746 mm. at Cape Horn.

The reductions made at Snow Hill (lat. 64° 22′ S.) at 0° and at sea level give a result of 740 mm. At Port Charcot (lat. 65° 04′ S.) the corresponding value was 744.87 mm., almost exactly the same as that obtained by the *Belgica* during her drift (744.7). The meteorologist of the *Français*, M. Rey, only once, in April, observed a maximum somewhat greater, at 760 mm.[b] The instruments on the *Gauss* recorded, below the polar circle, a mean of 740 mm. Finally, the readings made at Cape Adare, the southernmost of the observations taken, show 738.5 mm. In West Antarctica, however, the mini-

[a] It would be necessary to read the descriptions of the voyage to get an idea of the tenacity and courage devoted to these observations. At Port Charcot the readings of the instruments were punctually revised, even during the night and through all kinds of weather. During the *Belgica* drift the readings were made several times during the day, on the footbridge, etc.

[b] Doctor Charcot: Op. cit., p. 351.

mum mean was sufficiently high at the end of summer, that is, on the *Français*, in February and March, 734.8 mm., and on the *Belgica* in February, 735.7 mm. But the variations have everywhere a wide range; more than 45 mm. on the *Français* and 60 mm. on the *Belgica*. The most important fact in this connection seems to be the prevalence of frequent and very violent storms, with snow blizzards in all seasons, and they coincide with the sudden fall of the barometer when the wind blows from the north, principally in winter. Borchgrevink encountered ninety-two days of stormy weather near Victoria Land; at Snow Hill the barometer recorded 708 mm. during the gale of June 3, 1902;[a] at Port Charcot M. Rey reported 722 mm. in February and 718 and 717 in June and August.

During these storms, the wind blowing from the northward (northwest or northeast) brings some degree of warmth; but generally the cold polar breezes are most uniform throughout the Antarctic. Von Drygalski and Borchgrevink admit the existence of a continued austral anticyclone, which would remain steady near Cape Adare, but along the Antarctic Continent it would be to the eastward during the winter, and westward in summer.[b] We have thus to face conditions different from those in the arctic regions, influenced by the two cold poles near the polar circle in northeastern Siberia and on the North American Archipelago. In Antarctica the area of the anticyclonic south winds really expands during winter, reducing its radius in the summer, due to variation in uniformity of the temperature. The regions where the latest expeditions sojourned, between latitude 64° and latitude 72° S., are in the zones where the struggle is constant between the south breezes and those from the north. At Port Charcot, for instance, over 73 per cent of the observations refer to concurrent southwest and northeast winds, or approximate thereto. At Cape Horn, on the contrary, winds due to terrestrial rotation are dominant between southwest and northwest. On this side, however, there is a narrow belt of relative calm, serving as a passage from the temperate to the polar zone, where the fogs are much less frequent and the swell not so heavy. Over the known borders of Antarctica the winds from the pole (southwest or southeast) blow while the weather is clear and the barometer rises. Frequently they are strong (more than 15 meters a second) and always very cold. In exceptional cases they cause local phenomena, *foehn*, even in midwinter. At Snow Hill, for instance, Nordenskjöld verified a sudden rise of the temperature as high as 9.3°. At the end of the summer, toward Port Charcot, they are more regular from April to July (53 per cent of the July observations). On the contrary, northerly winds are always of a character strictly oceanic.

[a] O. Nordenskjöld: Op. cit., p. 143.

[b] Zimmerman: Ann. de Géogr. 1902, p. 385.

They are foggy and stormy, causing blizzards. No matter what the season, they cause a rise of temperature often exceeding 20°. They become more frequent in September, thawing time, and the season for the return and nesting of migratory birds. In certain latitudes these winds are constant almost all the summer. They make the approach to the pack ice everywhere very dangerous, and often imperil journeys over the ice bank and the coast glaciers.

As regards temperature, the great amount of glacial phenomena in the Antarctic makes it a region where there is really no summer. Observations taken at places generally uncovered alongshore and in the neighborhood of the Polar Circle have shown during the milder months figures much lower than might be expected, and comparable with those made by Nansen during the drift of the *Fram* with the arctic ice, beyond latitude 80° N. The higher mean recorded, from November to March, is the one at Port Charcot (lat. 65.04° S.), and this was less than 0°; that is, −0.39°.[a] At this station alone January gave a mean above the freezing point, namely, +0.48°. For the *Belgica*, that drifted westward of Alexander I Land as far as latitude 70.71° S.; for the *Gauss*, that wintered below the Polar Circle; and for the *Southern Cross*, the observations of which were taken at Cape Adare in latitude 71.18° S., the mean summer temperature ranged from −1.5° to −1.8°; therefore all were lower than the mean of −1.2° observed by the *Fram*, up to latitude 82° N. The December mean dropped to −2.2° for the *Belgica*. For the entire summer the observers of the *Discovery* recorded as low as −5.9°. Finally the extreme maximum everywhere has scarcely gone above 0°; the higher records are those of +6°, taken by the *Français* (April 23), and that of +3.5°, taken by the *Gauss* (January 2). The average of the maxima of 9.4° at Cape Adare (for February) corresponds to one month when the foehn blows were frequent.

The mean of the colder months from May to September was exceptionally low. For July the highest average for West Antarctide was that of the *Belgica*, −16.8°; the lowest average was −19.2° at Port Charcot and −20° at Snow Hill. The *Gauss* noted −19.1° for the entire winter and −21.8° in August. July results are still lower for the *Southern Cross* (−24.3°), and for the *Discovery* (−25.6°). The absolute minima of −35° and below have been frequent everywhere. No doubt it is to this persistent very low temperature and to the polar darkness and the almost constant fog that we must impute the havoc caused by polar anæmia in all expeditions.

Besides, the temperature everywhere is much more trying because of the many sudden changes in a single month, no matter where the

[a] The mean for July is +6° at Godthaab on the west coast of Greenland (64° N.).

region. At Snow Hill, for instance, the temperature on July 17 rose from −29.8° to +4.1°. At Port Charcot at the beginning of June there was a sudden rise from −21° to +3.5°. When these sudden changes occurred, which have had their equal in the summer, the explorers endured most painful hours; the unexpected thaws, generally coinciding with the storms and terrible snow blizzards, would dampen everything on shipboard; the tents and sleeping bags would become useless by the excessive humidity, and the men slept literally in ice water.

M. Rey noted that another important character of the antarctic climate is the high degree of saturation of the air into water vapor, although the tension might be weak. The mean noted on the hygrometer at Port Charcot was 86.3 per cent, 4 per cent higher than at Cape Horn; in July it went up to 92.4 per cent. Ordinarily precipitation occurs in the form of hard snow, which falls in small sharp crystals, even in summer time. The *Belgica* experienced two hundred and sixty days of snowfall. On the *Antarctic* snow was recorded on January 6, in full solstice, and on the *Français* there was snow on February 2, from the moment of their entrance into the polar region. Pouring rains are exceptional; they fall during the northern storms, at the change of season, sometimes with lightning and thunder.[a] The total depth of rainfall is slight. At Port Charcot it was only 376 mm., as compared with 1,360 mm. at Cape Horn. The maximum was from November to March (46 mm. in January as compared with 10 mm. in July).

The expeditions about to start will undoubtedly endeavor to determine precise results and to extend meteorological studies more than has so far been possible. A wide scope of observation is opened in matters relating to the polar currents, the intensity of gravity, atmospheric electricity, and terrestrial magnetism. Borchgrevink was able only by calculation to locate in a very general way the magnetic pole at latitude 73° 20′ S. and longitude 146° E. of Greenwich. He at least did not depend upon certain published hypotheses, one of which leads to the conclusion that the variation of the electric field in the Antarctic, as elsewhere, is in relation to the position of the earth on the ecliptic, and not in relation to seasons. It is greater when the earth is in the perihelion (winter in the northern hemisphere), hence we are led to regard the sun more and more as the source of electricity and of all forces.

SOUTHERN GLACIATION.

The constant low temperature in the Antarctic, never rising above zero, gives wide variety to ice formation. On the broad seas, always

[a] Doctor Charcot: Op. cit., p. 215. O. Nordenskjöld: Op. cit., pp. 143, 318.

rough, that inclose the polar region, the floating ice advances on the average as far as latitude 55° N. (latitude of Königsberg) and to latitude 35° S. toward Africa. All the expeditions from the time they encounter the first icebergs until they meet the inland continental glacier have traversed many series of ice formations, the study of which is highly interesting, not only because it has revealed rare and peculiar phenomena unknown in arctic regions, but also because it helps to explain what happened north of our continent during the Quaternary age. M. Ch. Rabot, in his excellent study in La Géographie (1907), emphasized the exceptional importance of observations on this subject. The observations by the *Scotia*, the *Discovery*, and especially by Doctor Philippi of the *Gauss*, and the fine photographs accompanying the account by Von Drygalski deserve to be closely examined.[a]

All observers agree that there is a general retreat of the glaciers in the Antarctic, a result in accord with observations in the Arctic regions and in glaciers of all latitudes. In West Antarctide the expedition of the ship *Antarctic* found traces of a larger extension of the ice over the banks of Orleans Strait, over l'Esperance Bay, and to the east of Graham Land, where the lowering of the ice cap measures 300 meters at the "nunatak" Borchgrevink.[b] At the summit of Mount Gauss large blocks of gneiss indicated to Von Drygalski that the ice had once covered the entire mountain. Judging by the apparent recent formation of the moraines extending to the foot of the mountain, he thinks that it is still in the glacial epoch.[c] On the coast of Victoria Land Borchgrevink found that the great ice barrier has retreated 50 kilometers since J. Ross and Scott figured it. Scott was impressed by the fact that the melting rate exceeded that of formation. His photographs also show the local importance of the summer streams, when the enormous masses of snow that the stormy winds have tossed about over the smooth surface of the inland ice are swept toward the base of the slopes without gain to the glaciers. The few clear places that the expedition visited all show recent moraines. The glacial terraces of Mount Terror, reaching to a height of 240 meters, suggest the impression that the great ice barrier at no distant time reached to that height, and its débris held by the shoals could be seen

[a] These photographs, very numerous and of perfect workmanship, not only show the various general aspects of the ice; they are an "anatomic" study of altogether new icy formations. See, for instance, the plates where are reproduced the different kinds of snowfall (snow sheets, rolling drifts, and dunes formed by the winds, etc.), and especially those that show the interior structure of the fresh-water ice (striated, ribboned, etc., p. 461).

[b] O. Nordenskjöld: Op. cit., p. 258.

[c] Zum Kontinent des eisigen Südens, p. 311.

as far as latitude 75° S. The formation of ice would actually be greater at the Balleny Islands, where the cold is not so intense, but precipitations are considerably greater.[a] Briefly stated, a new continent is emerging right before our eyes, from under the glacial ice. The glacier still hides the frontal moraines, partly covered by the sea, and which Doctor Charcot studied at Wandel Island.[b] If the receding of the ice should continue it may disclose the secrets of life in those regions during the Tertiary age.

Floating ice is the first formation met by the vessels coming from the north. This is chiefly ice débris, carried by the winds and currents far from their original source, floes of different sizes, or fragments from the ice bank. This drift ice sometimes almost completely covers the sea; it is agitated by the ocean swell, and swiftly floats in compact masses toward confined spaces, such as the straits of West Antarctide.[c] In the open sea as far as latitude 55° N. large icebergs drift; some of them, broken from the land ice, having a peculiar tabular shape, have attracted the attention of travelers. But who can describe these icebergs when upturned, their bases dented by fusion, cut into pyramids, into sharp peaks, and hollowed with caves or tunnels, where shines a strange blue light. It must be stated, however, that great floating icebergs are not numerous. The West Antarctide glaciers yield only fragments. Doctor Charcot saw no launching of large icebergs, and he does not believe that the great masses of ice, measuring 500 meters in height, can come from the region explored by the *Français*. Toward Victoria Land only two glaciers emissary from the ice cap, seen by Scott, gave forth icebergs. The Ross barrier would be the only known source of great icebergs, a region where there is activity to be compared to the great glaciers of Greenland. At Mount Gauss, Von Drygalski noted that the movement of the inland ice is very slow and the breaking not frequent. Here, moreover, as everywhere, the great blocks from the neighboring land rest long amid the coast ice and the ice bank before starting on their drift.

The ice bank visible from afar by its peculiar glimmer, called "ice-blink," incloses the polar lands in an almost continuous line, totally different from what takes place in the arctic seas. Seldom even in summer is any part of the shore found bathed by free water. Between latitude 62° and latitude 69° S., south of the Atlantic and Indian oceans, lies the long wall that forms the edge of the sea of ice, whence the drift ice is detached. This is the "icekant," generally several meters high. It affords access, always difficult, to a

[a] Scott: The Voyage of the *Discovery*, Vol. I, pp. 209, 383; Geogr. Journ., 1905, p. 353.

[b] Doctor Charcot: Op. cit., p. 74.

[c] Scott: Op. cit., Vol. I, p. 152. Doctor Charcot: Op. cit., p. 46.

platform of ice stretching out 3 to 4 kilometers in width, guarded by hummocks, with irregular crevasses, overturned during storms by frightful pressures, like that which swallowed the *Antarctic*. In the regions where the *Scotia* drifted (Weddell Sea), and also southwest of Alexander I Land, where the *Belgica* drifted many months, the ice bank is an immense plain with a thousand rugged hummocks as far as the eye can see. During winter and generally from May on the sea begins to flood beyond the borders of the ice and to rise on the shores that it waters, whether exposed or ice covered. M. Gourdon, of the Charcot expedition, observed the formation of this temporary ice bank, consisting chiefly of thin, sharp, angled blades, called "pancake ice," and of an uneven crackling crust of young ice. He believes that its thickness is due, not to freezing underneath, but rather to snowfall on the surface.[a] The moment that the temperature shows a sudden and prolonged rise, occurring even in winter, the ice bank partly melts and forms what is known as the "rotten pack," in which layers of soft and of solid ice lie one upon the other. Neither Andersson, of the *Antarctic*, on his trip from l'Esperance Bay to meet O. Nordenskjöld at Snow Hill, nor M. Charcot, on one of his journeys to the west of Graham Land, were able to traverse this "rotten pack."

The coast ice has a formation intermediate between that of the ice bank and of the fresh-water glaciers. This ice sometimes stretches in extensive sheets behind the pack to which it is held by an irregular edge; but nearly always it clings with very jagged outline to the high and rocky walled coast or crowds against the foot of the glaciers along the shore. In the midst of a body of sea ice, incessantly thickened by the falling snow, are incased stranded or capsized icebergs standing in bold fantastic relief, also débris, the whole cut by extensive crevasses. The gray-green tint of the sea ice farthest out, heightened by the layers of snow, as well as the tones of deeper hue, are caused by diatoms. Sledge journeys along this coast are very trying and exceedingly dangerous. Nordenskjöld on Ross Island and on King Oscar Land, Charcot in Flanders Bay, and Scott along Victoria Land, observed and described this formation.[b] Off Mount Gauss it is particularly remarkable because of its extent (35 km.); far out it becomes confused with the ice bank, while toward the shore it is separated from the continental glacier by a lofty slope of even descent down which the icebergs slowly slide and which seems to mark the shore line; above all in solitary grandeur towers the mass of fresh blue ice.[c]

[a] Doctor Charcot: Op. cit., pp. 140, 455. Nordenskjöld: Op. cit., p. 223.

[b] Doctor Charcot: Op. cit., p. 32. O. Nordenskjöld: Op. cit., p. 122.

[c] Von Drygalski: Op. cit., p. 302. A chart accompanying this account (p. 440) indicates the course of the ice from the bank pack to the inland ice, ice fields or icebergs, a conglomerate of fresh-water ice blocks, and the edge of the ice cap.

Along the shores of the antarctic lands, sometimes apart from the fresh blue ice, backing up against the high cliffs and covering in part the low-lying beaches, the coast glaciers occasionally break and plunge into the sea. Often joined at the foot they form a continuous ice wall several meters high, extending along the coast for 10 kilometers or more. Some of these glaciers, of an Alpine type, bore their way down a gorge from the heights or the inland ice. These Alpine glaciers are principally from Victoria Land. But usually the glaciers are rather of the Piedmont type, common in Alaska and other polar regions of North America. Both the *Français* and the *Discovery* expeditions had opportunities to study them in detail. The glaciers of West Antarctide near Gerlache Strait, etc., are covered by a fine or "powdered" snow, as M. Gourdon calls it, and amply frosted by the frozen sea spray. They form in the various shapes of a horseshoe, or a trench, or a small embankment and break their front edge into large blocks or prisms which become small icebergs.[a] Near Mount Lacroix one of these glaciers, backed up against two coast ridges, and supported by an invisible foundation, seems afloat on the water, like Ross's great barrier. Von Drygalski observed glaciers of this sort at Heard Island (Baudissin Glacier). But it is mostly along the extensive shore line of Victoria Land, a distance of more than 1,000 kilometers, that they are numerous and varied. They sometimes appear resting on the solid beach, sometimes grounded on the shoals, and sometimes with their front edge afloat.[b] Icebergs form from them all. Since the sources upon which they draw are meager, they may be deemed evidence of a former extensive glaciation; in some cases formidable evidence, for Mr. Scott measured some as long as 90 kilometers, such as the Ferrar Glacier.

Ross's Great Barrier, studied by Borchgrevink and Scott, seems to be a more imposing example of this phenomenon. It is really an immense coast glacier of fresh-water ice that recedes about 15 centimeters a day in spite of powerful pressure from behind. Its front part is afloat. The massive ice wall, 10 to 80 meters high, which forms its front edge, of which the splendid photographs taken by the *Discovery* expedition portray its different aspects, is but a frontal glacier, and not, as M. Bernacchi, of the *Southern Cross*, believed, the flank of a gigantic ice slide resting on the mainland. In fact, Captain Scott made a study, at Cape Crozier, of the junction of the barrier to the continent.[c] Moreover, it can be seen here how slightly the glacier is fed from above, compared with what has been observed on Greenland.

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[a] Doctor Charcot: Op. cit., pp. 451, 453.

[b] See M. Ch. Rabot's study, cited above.

[c] Scott: Op. cit., Vol. I, pp. 172, 191; Vol. II, p. 5, etc.

The Antarctic Continental Glacier is reached only after surmounting all these obstacles. From the summits of Brabant Island most of the peaks were observed by the explorers of the *Belgica*, and especially by Von Drygalski, from the summit of Mount Gauss. But on the famous journey from Cape Scott, in Victoria Land, the party succeeded only in traversing about 300 kilometers inland, while Nansen in 1888 had traversed the whole of the great Greenland Glacier. The border of this ice at least has been directly studied. On West Antarctide it covers Danco Land and King Oscar Land; to the east its edge, gone over by Nordenskjöld, extends from the shore across the ice bank to Christensen Island. It has a lofty slope, terminating in a great depression, and the surface of the higher bank appears much more united than the pack, with great series of blue-tinted crevasses at regular intervals.[a] In the vicinity where the *Gauss* wintered, according to Von Drygalski, Mount Gauss appears no more than a small break in the ice pack, which extends as far as the eye can reach, its edge forming above the coast ice that white perpendicular front wall already mentioned. A sounding made at the foot of the mountain, through the fresh ice, showed a depth of 170 meters.[b] Finally, on Victoria Land, the continental glacier is lodged against the mountainous coast barrier, as in the western part of Greenland, and it differs from that in few respects; only four extensions of the continental glacier have been located from Cape Adare to Cape Longstaf. There occurred here an evident sinking of the surface of the land ice, which Scott estimates at from 120 to 150 meters. Finally, it is to be noted that the ice block on the islands is in the peculiar form, observed by the *Belgica* and *Français* expeditions, of half of a large mound, of which the steep side is opposite from the usual direction of approaching blizzards (here the northeast). To these enormous solid dunes the significant name of "ice cap" has been given.

ORGANIC LIFE IN ANTARCTIC REGIONS.

The south polar flora has been studied principally on West Antarctide. M. Skottsberg, the botanist of the *Antarctic*, places its northern limit at about latitude 50° S., and distinguishes it from the austral flora, which is similar to that of South Georgia Islands. The islands are in a class which would have as characteristic vegetation 15 phanerogamic plants, among them the high bushes of tussok, photographs of which show slender and ligneous stems, grouped in large bunches. The landscape resembles that of Tierra del Fuego without trees. But the cryptogams predominate—4 ferns, 26 lichens,

[a] Nordenskjöld: Op. cit., p. 111.

[b] Von Drygalski: Op. cit., pp. 241, 311, etc.

and a number of mosses—and M. Skottsberg attributes their presence to a recent glacial advance.

In antarctic flora the phanerogamic plants are but rare and curious exceptions. Their extreme southern localities, so far as at present known, are: Cockburn Island and the neighborhood of Danco Land (lat. 64° 12′ S.), where M. Racovitsa made observations; the "nunatak" Castor on Seal Island, studied by the expedition of the *Antarctic;* and finally on Wandel Island (lat. 65.4°), where M. Turquet, of the *Français*, made interesting discoveries. The limit in altitude of plant life necessarily varies considerably. Skottsberg gathered mosses and lichens on Paulet Island at a height of 360 meters.[a]

The striking characteristics of this flora are the great abundance of coast seaweeds and of diatoms, which explains the swarming of animals in several localities and the numerous species of mosses (50, according to M. Turquet) and lichens, some of which are bipolar. But phanerogamic plants are not lacking. A species of small grass, *Aira antarctica*, observed by Racovitsa on Cockburn Island, and by Otto Nordenskjöld on the open shores of Orleans Canal, was also found by M. Turquet on Wandel Island. At Biscoe Bay, to the south of Antwerp Island, this plant, he says, forms veritable prairies among the low hills. Among the mosses it is associated with a rather undeveloped species of Caryophille, which he saw for the first time, the *Colobanthus crassifolius*, its diminutive greenish flowers being hardly distinguishable from the leaves.[b] These two plants are found in the flora of Tierra del Fuego; they should be regarded as wanderers from the austral flora in the antarctic realm, in the midst of climatic conditions entirely unfavorable. Mount Gauss, isolated as a nunatak amid boundless ice fields, and far from any center of propagation, has not presented them to observers.

The rigorous antarctic landscape of ice and rocks is enlivened by a numerous fauna of cetaceans and birds peculiar to the region.[c] The great abundance of food in the water—fishes, crustaceans, diatoms, and "plankton"—attracts the seals and birds to the ice bank, particularly to its very sea edge. During the comparatively warmer months, however, they live on clear spots along the shore, and even on the edge of the land ice. It is here, principally, that the birds propagate. Thus there are observed migrations of great geographic and practical interest in which but a few species are not included.

The fauna in this locality differs from that of the islands of the south Indian and Atlantic oceans, and that of Tierra del Fuego, which may be classed as "subantarctic." The fauna of Victoria Land

[a] Geogr. Journ., 1904, pp. 655, 663.

[b] Doctor Charcot: Op. cit., pp. 434, 435.

[c] De Gerlache: Op. cit., p. 190. Doctor Charcot: Op. cit., p. 419 (Turquet).

is essentially the same as that of West Antarctide. According to observations by the *Southern Cross* expedition, it includes few bipolar species, except among the crustaceans. Finally, certain littoral species of fishes (Nothotenidæ) and other marine animals, resembling the survivors of the Tertiary age found along the shores of South America and southern Australia, support the hypothesis of a former connection between the polar lands and those continents. This question, however, is still uncertain, as we have seen. Whalers and seal hunters were the pioneers who opened the route for the scientific expeditions toward the South Pole, and the present-day continuance of these enterprises serves as good evidence of the abundance of large animals in these southern seas. One of the latest and most daring of polar game hunters, Larsen, who served as captain of the *Antarctic*, has gone with the definite object of establishing an oil station in the antarctic islands below South America.[a] Any present and future discoveries in this direction will no doubt benefit primarily the Australian and Argentine interests, whose business headquarters are in the vicinity. There is especially to be noticed, in partial justification of this suggestion, the support granted by the Argentine Government to all subpolar expeditions bound for West Antarctide, a support always as valuable as it is willing. But let us remember that material interest in expeditions of such profit to science is never to be discredited.

The "whale" proper has not been observed in antarctic seas, but the Megaptera (jubartes) and the Balenoptera (rorquals) are of frequent occurrence. Seals of rich fur are abundant on the ice bank, living in small groups or families on the surface. During winter, however, they spend part of their time under the ice in localities where the sea water is less cold and where food is plentiful, their communication with the outside world being merely by means of holes which they purposely keep open. The largest of these animals, the sea elephant, sometimes 6 meters long, and the sea leopard, noted in all the localities visited, but really of rare occurrence, also belong to the subantarctic fauna, and are found, for instance, at South Georgia. Three varieties are peculiar to the south polar region. The Weddell seal (*Leptonychotes* W.), with its iron-gray spotted skin, a great fish eater, and the "crab-eater" (*Leptodon carcinophagus*), which lives on varieties of shrimps of the genus Euphausias, very numerous in many localities, are the most common species. The Ross seal (*Ommatophoca Rossi*) is the species that has been found farthest south.[b]

Among the birds, some of very high flight, the petrels and the albatross, belong to the subantarctic fauna. All the species show

[a] A precedent followed by M. Ralier du Baty, member of the *Français* crew.

[b] See Scott's account, Vol. II, Appendix.

varieties more particularly polar, and all of them, associated with the manchots, give to the animal life of the ice bank and the border of the antarctic lands a very special aspect.

Coming from the north, the first bird to appear is a small petrel, the cape pigeon or damier, which is quite numerous. After this come the terns, six varieties of the petrel, including the *Megalestris*, and the great petrel, a genuine vulture of the south pole, with its wing spread of more than two meters; finally the cormorant (*Phalocrocorax atripex*), the sea gulls (*Larus dominicanus*, etc.), the chionis, and the manchots. All these animals are webfooted excepting the chionis, by which is demonstrated their dependence on the sea element that nourishes them. Almost all the birds, like the seals, are destined to migrations that take them far from land from the time when the cold extends and thickens the coast glaciers; that is, from May until the first half of November, when they go south again to lay their eggs. The rookeries then suddenly spring to life, and colonies of various species come to dispute a place for their nests of seaweed (the cormorants), of mosses and lichens (the sea gulls), or of plain sand and rocks (the terns). Only the cormorants, the sea gulls, and the chionis, that can fly far for their food, remain on land during the winter. The albatross and the petrels, which are exceedingly carnivorous, and consequently great game thieves and scavengers, follow the great migration. When the seals and nearly all the birds abandon these regions, absolute desolation remains; the polar lands lie dead beneath their mantle of pitchy darkness, fog, and ice.

The penguins, far more numerous than the other birds, are the principal friends of the explorers, whose table they abundantly supply. All descriptions of the country are filled with details regarding their habits and characteristics, especially noting the good nature, watchfulness and curiosity of these interesting birds. Thousands of photographs portray all the phases of life in their well-established communities. On West Antarctide the penguin of Adelie (*Pygoscelis Adeliæ*) and the papou penguin (*Pygoscelis papoua*) are the most common. The *Belgica*, *Français*, and *Antarctic* expeditions have minutely studied the penguin colonies. The antarctic penguin (*Pygoscelis antarctica*) has been seen in small groups in Belgica Strait and on Wandel Island. The *Français* failed to find in this locality the great emperor penguin (*Aptenodytes Forsterii*), common enough toward Mount Gauss and Victoria Land.

The insect family has very few representatives. The explorers of West Antarctide discovered a wingless fly, the *Belgica antarctica*, which lives among the mosses, three or four varieties of Acariens and the snow flea.[a]

[a] De Gerlache: Op. cit., p. 151. O. Nordenskjöld: Op. cit., p. 295.

Fishes, on the other hand, abound in great numbers and many species are edible. The same may be said of mollusks, principally among which is a variety of Patelles on which the sea gulls feed. The crustaceans are represented in the main by a small shrimp of the genus Euphausias, on which the seals, "crab-eaters," and penguins feed.

Genera of inferior rank are numerous and the specimens brought back, as well as local studies, have augmented natural history by more than one chapter, and cleared more than one mooted point in paleontology. Knowledge in microbiology should also be greatly enhanced, as is demonstrated by the first observations of Doctor Charcot on south polar materials.

CONCLUSION.

These are the discoveries in Antarctica made by the scientific expeditions in the last five or six years. The necessity for further research in this region has been shown, and the directions this research should pursue. In the meantime plans for future studies are in hand.

The knowledge gained by the various recent expeditions and the experience and results of his first voyage have guided Doctor Charcot in selecting the locality for his work and in preparing a complete plan of studies, to which the Academy of Sciences has given its hearty approval. Two English vessels, commanded by Captains Scott and Schackleton, are again bound for the vicinity of Victoria Land and Ross Sea. Mr. Bruce is about to visit the Weddell Sea, on the *Scotia*, for the third time. Finally, M. Arctowski, formerly one of the ship's officers of the *Belgica*, is to attempt a circumpolar exploration, in accordance with the programme adopted by the Brussel congress. M. Charcot has therefore chosen the great region to the southwest of West Antarctide, between 60° and 140° W. of Paris. It is below Alexander I Land and Peter I Land, on this side of the southern ice bank, barely approached by Bellingshausen and by Wilkes, that will probably be richest in discoveries. After exploring the fossiliferous beds of Mount Bransfield and of Seymour Island, where specimens will be gathered, which will be stored at Ushuaia or at Port Charcot, the expedition will try to establish a connection between Loubet Land and Edward VII Land. It is planned to spend at least one winter on land, and journeys over the ice will be made as often and as far as possible, not for the glory of long distances traveled, but to inspect a large area of ice.[a] A commission of the Academy of Sciences decided on February 4 to grant M. Charcot its unlim-

[a] Doctor Charcot: Programme de l'Expédition française au Pôle-Sud, a pamphlet of 12 pp., 1908. The chief of the expedition intends to supply provisions by means of a tender. He has closely studied methods for the exploration of the distant ice fields, and will try heavy automobile sledges, which will perhaps be useful for nearing the pole.

ited support, and a committee of twelve persons was appointed to draw up a detailed programme for the expedition with a view to results already secured. The Muséum d'Histoire Naturelle, the Ligue Maritime Française, and the Institut Oceanographique have combined largely in the preparation and the selection of the materials for traveling, for observation, and for laboratory work and have also aided in giving preparatory instruction to the observers. The Government finally has cooperated, at the instance of the minister of public instruction, through a reasonably substantial appropriation. Much better prepared and equipped than the *Français*, the *Pourquoi-Pas* will carry officers and crew and an outfit in part new, but as full of physical and moral courage as the former expedition.

In conclusion, may we emphasize the scientific reasons that should enlist the liveliest interest in this enterprise. They have been masterfully presented by the committee of the academy and by M. Charcot himself.[a]

The south polar region, almost entirely covered by ice and surrounded by an open sea, is affected much less by distant foreign influences than the arctic basin. Winds and currents from outside sources do not create obstacles such as those found in the north on the west and east of Greenland, for instance, or between the west and east shores of the North Atlantic. The cold temperature pole and the magnetic pole seem there reasonably near the astronomic pole. The isolation, no doubt recent, of the antarctic islands and continent from the rest of the world has still been so complete that conditions of locality and of organic life are unique and uniform. It is a field for research unlike any in the world, not because of the local data that can be secured, but from the point of view of the general physical structure and history of the earth.

The question of the union of the antarctic lands with the southern part of the continents, which has not yet been definitely solved, opens a field of valuable research. The true explanation of the pointed extremities of America and Africa will furnish another object for observations. MM. Lacroix and Lapparent insist, in the written instructions to Doctor Charcot, on the need for determining how far the petrographic limits of the Andes and of America extend into the Antarctic. From samples of rock brought back by the latest expeditions, it seems to cover the whole end of West Antarctide; but a microgranite found on Wandel Island would seem to indicate that there begins a different province, of which Victoria Land is a part. Therefore it is easy to understand of how much importance is a detailed

[a] Institut de France, Académie des Sciences. Instructions pour l'expédition antarctique organisée par le Dr. Jean Charcot. 12mo, 48 pp., Paris, Gauthier-Villars, 1907. J. B. Charcot: Pourquoi faut-il aller dans l'Antarctique? 8°, 16 pp., Paris, 1908.

study of Alexander I Land and the region that adjoins it on the west.[a] In this connection, on examination of the geological collections from West Antarctide from the Patagonian and Cape Horn expeditions, M. Gaudry has drawn conclusions worthy of deep consideration.[b] The character of the Patagonian Iocene and Miocene faunas strengthens his belief in the existence during the Tertiary period of "an immense antarctic continent, with rich vegetation and warm climate," of which the polar lands formed a part. The latest period of depression which has by degrees isolated these lands, and the invasion of ice that has modified or stopped the development of life, should be placed about contemporaneous with the formation of "pampas;" that is to say, after the Pliocene period, which witnessed an invasion as far south as Patagonia of northern animals (mastodon, tapir, etc.), until the beginning of the Quaternary, when man is known to have lived in this region. Research and study in the Orkneys and South Shetland and in Antarctica, on the ooze and clay deposits and formations of the same period as the pampas, is an undertaking of deep interest. M. Charcot says it should be as interesting as a trip to the moon.[c]

Since the south polar region was separated from the continents and began to be covered by the ice, life on this part of the globe has in fact undergone such special evolution that theories about the bipolarity of species seem to be at present destroyed. There remains to be determined the time of separation and the links of this evolution that have disappeared. Have all the micro-organisms which were found by the observers of the *Français* scattered over all the south polar region been dead for thousands of years, or are they still developing under conditions of temperature that would ordinarily prevent life? On the other hand, beneath the ice must lie hidden a flora that has disappeared, and also the immediate ancestors of the present living animals, which could not survive such severe cold. Here must be buried an extinguished world, a "whole system of life absolutely unknown, but seen heretofore, dead from its inability to go farther north on account of the cooling of the earth."[d] Since all research on the mineral formation of the globe and on conditions of life may lead to unanticipated practical results, it may be seen that these suppositions are not altogether speculative.

Although singular conditions have prevailed on the physical structure of the globe in the antarctic with regard to previous studies, these will continue under far more propitious circumstances. For the work of observing the tides, and for researches on solar and lunar

[a] Lacroix: Instructions, p. 11.

[b] Gaudry: Instructions, pp. 19–29.

[c] Doctor Charcot: Pourquoi faut-il aller au Pôle-Sud, p. 14.

[d] Doctor Charcot: Ibid.

attractions, the large southern seas, bordered by an almost regular belt of ice, are most favorable localities. Likewise, investigations on the composition of the air, on terrestrial magnetism, and on the intensity of gravity, so full of possibilities in the study of the form of the geoide and the gaseous envelope, can, due to the immobility of lands and ice fields, be studied as in a laboratory. The arctic polar basin does not offer as great advantages.

The best results, of course, may be obtained by the establishment of a friendly cooperation between all the observers of different nations preparing for study in the antarctic region, and this should be done by laying aside the cause of national competition in the general cause of science.

Appendix.

THE SHACKLETON EXPEDITION.

[The following account of the achievements of Lieutenant Shackleton is copied from The World's Work, May, 1909, Vol. XVIII, No. 1. (Doubleday, Page & Co., New York).]

Lieut. Ernest H. Shackleton, of the British Navy, left London on July 30, 1907, in search of the South Pole; and he has returned after breaking previous records by 352 miles and reaching a point 111 miles from the pole itself. The party sailed in the ship *Nimrod* 2,000 miles due south of New Zealand, and were left ashore in the frozen wilderness at McMurdo Sound, where they erected the wooden house they had brought in sections from England. From this point they traveled 1,708 miles inland, giving one hundred and twenty-six days to the expedition. They crossed several mountains and reached a plateau 10,000 feet above sea level. After passing the south magnetic pole, at a latitude of 72° 25′, longitude 154°, a party of four turned aside to ascend the great antarctic volcano, Mount Erebus, 13,120 feet high, the southernmost volcano in the world. This they ascended for the first time, and found its crater to be half a mile in diameter, and 800 feet deep. It was throwing up great volumes of steam and sulphurous gas to a height of 2,000 feet.

Assembling at the base station at Camp Royd, a second party, including Lieutenant Shackleton himself, with four Manchurian ponies, started on October 29, 1908, for a final dash for the pole. They were stocked with provisions for ninety-one days. The winter being mild, the lowest temperature they encountered was 40° below zero, Fahrenheit. At irregular intervals, they made depots of food for their return. The snow was so soft that the ponies frequently sank in up to their bellies. One by one they had to be shot, as they were attacked by snow-blindness, and were needed for food.

At a latitude of 85° the party discovered an enormous glacier, 120 miles long and approximately 40 miles wide, running in a south-southwesterly direction. Beyond the glacier, they came upon a great plateau 9,000 feet above sea level, which rose gradually in long ridges to 10,500 feet. They had left all the mountains behind and had entered upon a great plateau, which apparently stretched unbroken to the pole, when on January 9 of this year, in the midst of a violent blizzard, the whole party, weakened from the effects of a shortage of food, fell ill with dysentery and were forced to turn back. This, the most southerly point ever reached, was in a latitude of 88° 23′, longitude 162° east.

The violent blizzards raging on the plateau appear to disprove the supposition that an area of atmospheric calm surrounds the pole.

The achievements of the expedition are many and varied. Eight mountain chains were discovered, and 100 mountains surveyed. Many systematic zoological, meteorological, and botanical observations were made by the experts attached to the party. The chief vegetation was in the shape of large sheets of a fungus-like plant in the lakes, many lichens, a few mosses, and seaweed of two kinds. The auroral displays were exceedingly brilliant throughout the winter, one of the most striking forms being a horizontal bar with draped curtains extending across the sky, sometimes stationary, and sometimes moving with great rapidity across the heavens. In his report Lieutenant Shackleton also speaks of "racing cascades of luminescence, which traversed the length of the heavens with remarkable speed." Observations were also made in meteorological optics and atmospheric electricity, together with chemical and physical studies in connection with the freezing of the sea surface. Good moonlight photographs were obtained of the eruption of Mount Erebus. And it was furthermore ascertained that most antarctic bergs are snow bergs.

Although little more than the shore line has been explored, it is believed that the antarctic continent is as large as the whole of continental Europe. As a result of this expedition, the entire map of the antarctic regions will have to be changed. The expedition, by endurance and by achievement, ranks with the great north polar explorations.

SOME GEOGRAPHICAL ASPECTS OF THE NILE.[a]

[With 5 plates.]

By Capt. H. G. Lyons, F. R. S., F. R. G. S.,
Director-general of the Survey Department of Egypt.

The geographical exploration of the basin of the upper Nile was actively prosecuted during the second half of the last century, but the Mahdist rebellion closed this region to travelers in 1884, and for the next fifteen years but little could be done. In 1899 the capture of Omdurman and the defeat and dispersal of the Dervish forces once more opened the southern Sudan to European activity. In the meantime Egypt, under a stable government and an efficient organization, had increased marvelously in economic prosperity. Improvements in the irrigation system enabled the cultivator to receive regularly the water which he required, and the construction of the Aswan reservoir furnished a supply of water which sufficed, with strict economy, to meet the most pressing needs of the country and its rapidly increasing cultivation during the low stage of the river. But more water was necessary if the waste lands on the northern margin of the delta were to be reclaimed and cultivated. The Blue Nile, which falls rapidly in the autumn months, was obviously useless for this purpose, so that the study of the White Nile and its tributaries was the first step toward the solution of the problem.

During the past nine years much has been done in this direction, and now the main characteristics of the various portions of the river system have been ascertained. It may be of interest, therefore, briefly to lay the results before the society.

In Egypt, from the earliest period of antiquity, the annual flood of the Nile was recognized as the most important phenomenon of the year, and it attracted the attention of the dwellers in the valley both on account of its importance to them and from its occurrence in a region where the climate is practically rainless. According to Herodotus, the ancient Egyptians considered the river as flowing from two

[a] Read before the Royal Geographical Society, June 29, 1908. Reprinted, by permission, with author's corrections, from The Geographical Journal, London, Vol. XXXII, No. 5, November, 1908. Plates 1 to 4, photographs by E. M. Dowson; plate 5, photograph by Doctor Borchardt.

springs in the neighborhood of Philæ Island at the head of the first cataract, although this legendary source can not have coincided with their experience, since from very early times they were acquainted with its Nubian valley, and therefore knew that the true sources lay to the south of this again. But these southern regions were poor and inhospitable as compared with the fertile flood plain and delta of Egypt, and beyond raiding them for slaves and cattle and levying a tribute upon the inhabitants, the Egyptians interested themselves but little in the upper reaches of the river.

In the course of the eighteenth century the sources of the Blue Nile were discovered, and the cause of the annual flood was correctly determined to be the summer rainfall on the table-land of Abyssinia. In the nineteenth century the White Nile was traced to the lakes of the equatorial plateau, and the geography of its basin was sufficiently elucidated to enable Lombardini, in 1865, to sketch out the broad lines of the hydrography of the Nile.

During the last quarter of the nineteenth century the rapid increase of prosperity in Egypt, which was due to the establishment of order in the country and the introduction of administrative reforms, directed attention to the lower reaches of the river, while the Mahdist rebellion closed the Sudan to travelers. The irrigation of the country had been organized and developed so that not only were large areas of waste land brought under cultivation, but land which formerly bore but one crop in the year, produced two and even three when the water of the Nile was supplied regularly throughout the year instead of at the time of the inundation only. But at the same time that the demands of the cultivator have been constantly increasing, Egypt has experienced an unusual shortage of water, caused by the long series of exceptionally low floods which have occurred of late years, one alone since that of 1896 having been above the average, so that great difficulty has been experienced in furnishing the quantity of water needed for the crops.

The valuable cotton crop, which is sown in March and April, and which is picked in September and October, needs a regular supply of water in May, June, and July, when the river is at its lowest and the flood has not yet arrived; consequently the irrigation engineers have been compelled to husband the water in every available way that could be devised in order to meet as far as possible the requirements of the early summer months. But a larger supply was urgently needed, and directly Omdurman had been taken and the Mahdist rebellion had been crushed, the investigation of the upper Nile was vigorously pushed forward in order to see how the low-stage supply of the river could best be increased. To these needs we owe the great addition to our knowledge of the regimen of the Nile and its tributaries which has been gained during the last eight years.

Many of the views which were formerly held have been modified as new information was accumulated, but we may now say with some confidence that the regimen of the basin is well known in its broad outlines, and although much detailed work remains to be done, although many lines of investigation are as yet almost untouched, it is possible now to describe the more striking geographical characteristics of the river, and to indicate some of the deficiencies in our knowledge which those who have opportunity for observation may be inclined to make good.

There are three principal and characteristic factors of the Nile regimen which exercise a marked effect upon it as a whole, and influence to a greater or less degree each portion of the river system; but each portion also has its own peculiarities, which may greatly alter its reach of the river, and may produce effects which in turn influence other areas. It will be convenient to deal first with those factors which are of wider influence, and afterwards with those which affect a more limited area. Of the former there are three:

Firstly, the plateau of the equatorial lakes and the Abyssinian Plateau—for both of these receive a heavy rainfall and supply the whole of the water which is carried by the Nile and its tributaries, that which falls on the Sudan plains being so little that it may be considered to be practically negligible as a source of supply for the river; secondly, the rainless, or at least arid, conditions which prevail over a very large proportion of the basin, since even over the greater portion of the Sudan plains precipitation is very moderate in amount; thirdly, the very low slope of the basin, which is such that an altitude of 1,500 feet above sea level is not reached on the White Nile until a point 3,000 miles from the Mediterranean, near Gondokoro.

Though each portion of the river has its own peculiar character, these three factors, a heavy localized rainfall, aridity in other parts of the basin, and a valley of low slope, are those which exert the greatest and widest influence.

When we begin to study the basin of the Nile as it is presented to us to-day in the latest maps and in the descriptions penned by travelers in recent years, we find that in some respects this great river departs from the normal type, and exhibits peculiarities which it is of interest to investigate. Rivers have usually a steep slope near their source, which gradually becomes less as lower levels are reached and the eroding power of the water diminishes; beyond this follows a region of deposition, where the inclination of the valley is very slight, and the river flows slowly through alluvial plains which it has formed in the course of ages; but this plain tract occurs in the Nile system at two very distant points, the valleys of the Bahr el Jebel and the White Nile, and the valley of Egypt.

If we consider the longitudinal section of the Nile, which has now been leveled from the Mediterranean to the Victoria Lake (with the exception of two short reaches, together not more than 140 miles in length out of a total length of about 3,500), we find that both the Victoria Nile and the Semliki River descend very rapidly from the equatorial plateau in several series of rapids, interrupted by level reaches, until Gondokoro or Mongalla on the Bahr el Jebel. Then there follows a length of 1,060 miles in which the river falls only 180 feet, or at the average rate of only 2 inches per mile. Beyond this point the slope again increases, and the river descends some 800 feet in 1,200 miles in passing the several cataracts between Khartoum and Aswan, after which it flows through Egypt, with a fall of from 5 to 6 inches per mile. Thus there is first an unnavigable portion, then a long and easy waterway which is separated by the cataract portion, which is partially navigable, from the valley of Egypt where the Nile has furnished the best means of communication. The comparatively recent movement of blocks of the earth's crust on the equatorial plateau is shown by the very moderate amount of weathering which has as yet taken place, and by the very incomplete development of the drainage systems there: lakes, marshes, and river reaches of low slope, which are choked with reeds and water plants, alternate with rapids and rocky stream beds, down which the water rushes to deposit its load of detritus in another lake or plain tract lower down. In this way the water which flows over the Ripon Falls pours down 60 miles of rapids, and then joins the still waters of Lake Choga; at Foweira 50 miles of rapids begin, which end at the Murchison Falls, 120 feet high; and immediately beyond these the material eroded from the rocky bed and brought in by tributary streams is forming extensive mud flats where the Victoria Nile enters Lake Albert. The Semliki River, after flowing northward for some 50 miles from Lake Albert Edward, plunges down a series of rapids until it reaches the level of the Albert Lake. Thus far, then, the Nile may be said to be in its mountain tract, as it scours its way down the gorges which it is carving out in the masses of granite and gneiss which form the plateau. One hundred and thirty miles beyond the Albert Lake the Nile again plunges down 90 miles of rapids, the last step of the lake plateau, after which it flows gently through the plains of the Sudan.

The Sobat, the Blue Nile, the Atbara, and the Mareb, or Khor el Gash, all rise on the Abyssinian Plateau at altitudes of from 6,000 to 8,000 feet above sea level, and pour down their deep-cut gorges until they reach the plains of the Sudan, where they have excavated meandering channels in the alluvial plain.

The quantity of water supplied by these two great gathering grounds would be very large but for certain geographical conditions

which reduce that from the equatorial plateau to an almost constant supply of about 12,000 or 14,000 cubic feet per second, while the Abyssinian rivers, on the other hand, must furnish about half a million cubic feet per second in a high flood.

In the majority of rivers the volume of water which they discharge increases from a very small amount near their sources to a maximum near the point where they empty themselves into the sea or an inland lake. With the Nile it is quite otherwise; not only has its volume a very marked seasonal change of volume, but from point to point of its course it varies greatly, now increasing and now decreasing as local conditions affect it. The maximum is reached when the Atbara joins the Nile, and from this point onward the volume diminishes by evaporation, seepage, and by the utilization of the water by the agricultural population of Egypt. The whole of this supply is furnished by a seasonal rainfall, which oscillates during the year from about 15° south of the equator to 15° north of it; in January British Central Africa receives its heaviest rainfall; in Uganda, the spring maximum occurs in April and May, while during July and August 60 per cent of the year's rain falls on the Abyssinian Plateau; in the autumn the rain belt travels southward, again passing the equator about November and reaching its southern limit in January. Thus the equatorial plateau has two rainy seasons and two dry seasons, while the Abyssinian Plateau and the Sudan plains have a single rainy season in the summer months. North of Berber practically no rain falls, and that which the northern part of the delta receives in winter does not reach the river.

The supply effectively furnished to the river at different points by this rainfall is shown in figure 1, where each division of the vertical scale represents a discharge of 35,300 cubic feet (1,000 cubic meters) per second. Each of the discharge curves south of Dueim depends on a few measurements only, but the diagrams for these stations have been corrected as far as possible with the aid of the daily gauge readings; those for Dueim, Khartoum, Atbara, and Wadi Halfa are from numerous actual measurements. The flood of the year 1903, which these diagrams represent, was in volume 11 per cent below an average flood at Aswan.

The diagram is exceedingly instructive, for we see that, while the change of level of the Victoria Lake makes but little difference to the discharge, a very marked seasonal variation occurs at the Murchison Falls, where the low-stage volume is about 21,000 cubic feet per second, compared with 56,000 in flood, and this increase is due to the July-November rainfall on the northern edge of the plateau, since upstream of Foweira the water level of the Victoria Nile varies but little. At Wadelai the level varies with that of the Albert Lake, and the discharge shows a maximum toward the end of the year. At Gondo-

koro there is a well-marked maximum in September corresponding to that already noted at the Murchison Falls, and is, like it, due to the rainfall on the northern edge of the plateau. But little of this water ever reaches the White Nile, for as the level of the Bahr el Jebel rises, the plains of the valley are flooded, and the discharge into Lake No, 500 miles to the north, hardly varies throughout the year. This 12,000 cubic feet per second represents the whole of the effective supply furnished to the White Nile by the rainfall of the equatorial plateau, so that the run-off at this point amounts approximately to one-tenth per cent of the rainfall. The Bahr el Ghazal and the Bahr el Zaraf together contribute from one-sixth to one-third of that furnished by the Bahr el Jebel, and their combined discharge represents the whole of the supply which is not derived from the Abyssinian Plateau.

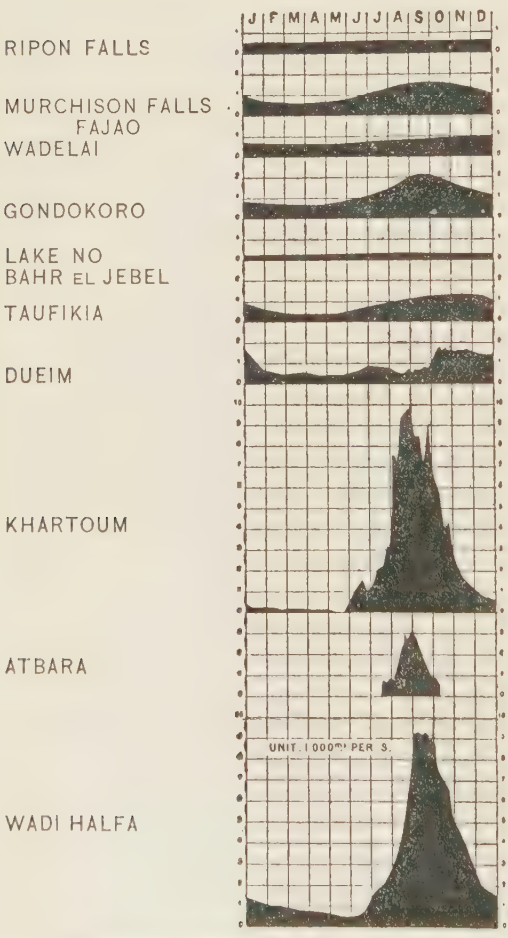

Fig. 1.—Volume discharged by the Nile.

In the Sobat River we have the effect of the Abyssinian rains, but the maximum is only reached in December, owing to the delaying effect of the plains of the Pibor River, a branch of the upper Sobat, which are flooded by the summer rains, and are only drained off gradually.

The White Nile carries the volume supplied by the Bahr el Jebel, Bahr el Zaraf, and Bahr el Ghazal, together with whatever is supplied by the Sobat—that is to say, from about 14,000 cubic feet per second as a minimum to about four times that amount in flood time. But the slope of this portion of the Nile north of its junction with the Sobat is so low that the flood water of the Blue Nile rising rap-

idly ponds back that of the White Nile, and so long as the former is discharging more than 180,000 cubic feet per second but little of the White Nile water passes forward; it floods its own valley, forming a reserve supply, which drains off in November and December, when the level of the Blue Nile has fallen. Thus the equatorial plateau has no effect whatever on the flood in the Nile Valley north of Khartoum, but furnishes the bulk of the low-stage supply.

From Khartoum northward the discharge diagram takes a wholly different form, for the Blue Nile is fed by the rains of Abyssinia, which are strictly limited to a short season, and may be considered as almost restricted to the months of June, July, August, and September, in which 15 per cent, 30 per cent, 30 per cent, and 15 per cent of the year's rainfall occur, respectively. Consequently the river rises rapidly to its maximum level, which it reaches at the beginning of September, and then falls almost as rapidly. The Atbara is supplied by the same rains, and has a similar regimen, but falls somewhat earlier, so that the maximum level at Wadi Halfa and Aswan is also reached in an average year at the beginning of September.

The Wadi Halfa diagram shows the resultant effect of the two sources of supply—the Blue and White Niles. At the beginning of the year the discharge of the Blue Nile has diminished to a very small amount; the Sobat is furnishing a considerable supply to supplement the constant volume delivered by the Bahr el Jebel, and to increase the water which had been stored in the White Nile Valley, and which is now rapidly running off. From this time until May the volume of the Blue Nile and that of the Sobat decreases rapidly, the water stored in the White Nile has drained off by the end of January, and all that is available for Nubia and Egypt is the water from the equatorial plateau supplemented by such small supply as the Sobat and the Blue Nile may still bring down, as well as by a certain amount which drains back into the river from the flood plains and the sandstone which forms the valley sides. This then is the time of Egypt's greatest need, and increasing cultivation has necessitated the construction of reservoirs and regulating dams by means of which the surplus water of November and December can be stored up and supplied during the period of deficiency which lasts through May, June, and July. It is easy to see now what will cause deficiency in the low-stage supply, since that which arrives from the equatorial plateau is constant throughout the year; weak rains in Abyssinia, which end earlier in the autumn than usual, will cause the Sobat and the Blue Nile to fall to their minimum early in the spring months; the low flood will have held up less water in the White Nile Valley, a less thickness of alluvium in the valley will have been saturated, so that the variable sources of supply will be much reduced. If such

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a state of things occurs in successive years, the average level of the water table in the valley will fall, and this also will act prejudicially. History records that on more than one occasion the Nile at Cairo was so low that it could be forded in the early summer, which was doubtless due to such a chain of causes as that above described, assisted by such a distribution of sandbanks at Cairo as allowed the water to spread over a wide bed without forming a definite channel; for series of low floods due to weakness of the Abyssinian rains are common, but a diminution of the water of the river to such an extent has rarely been recorded.

It will be seen that, with such a reduction of the water supply in the first half of the year, continuous cultivation of the arable land was impossible until engineering works had been constructed to raise the level of the water sufficiently for it to flow into the perennial supply canals, and until reservoirs existed in which the surplus water of the autumn could be stored for later use. Previously the flood water was led on to the flood plains by canals, so that it might there deposit the silt which it carried in suspension and soak the soil in preparation for the crop which was to follow; on this newly deposited silt and the water-soaked land the seed was sown after the flood water had drained off. Land in Egypt which was not watered by the flood could not be cultivated for that year unless it was situated on the bank of the river, or wells were sunk in the alluvial plain so that the crops could be watered artificially. Hence the flood was all-important; and one that did not reach the requisite level caused scarcity, want, or even famine. Modern skill has greatly changed these natural conditions until the whole of the delta, and a large part of the valley north of Assiut, receive water throughout the year with the aid of the regulating dams at Assiut, near Cairo, and at Zifta, which enable the water to be turned into high-level canals; the Aswan reservoir furnishes a supply at the season when the normal volume of the river is insufficient for the demands made upon it by the present amount of cultivation. Finally, the regulating dam which is now being constructed at Esna, in Upper Egypt, will render it possible to turn the flood waters on to the higher lands in the province of Qena which are not watered by a low flood, and so insure their yearly cultivation.

Man has thus so altered the conditions of the Nile supply that in future the flood will no longer have the same preeminent importance that it has hitherto enjoyed. At the time of full flood there is always more water than can be utilized, and now the Esna work will enable the high land to be flooded even in years of deficient supply. It is the low-stage supply on which the cotton crop depends that is now most anxiously studied. If the rainfall has been heavy and consequently the flood has been large, the springs in Abyssinia provide

more water to the Sobat and Blue Nile, and these two variable factors in the low-stage supply supplement efficiently the volume of the White Nile; if the rains have been weak or have ceased earlier than usual, the springs will diminish early, and the Sobat and Blue Nile will give but little help in the early months of the year. It is under these conditions, when the flood of the previous summer has been deficient and the low-stage levels are abnormally low, that the rainstorms, which occasionally break on the Abyssinian plateau from November to March, are of inestimable value. Their importance has hardly been generally recognized as yet by those interested in Egyptian agriculture, but the investigation of the meteorological conditions on which these storms depend is being actively prosecuted, and observations from the Nile basin and the surrounding countries are being studied. The winter of 1906–7 furnishes an instance of the importance of these winter rains, for after a flood which was 30 per cent below the average, rain in February and March increased the volume of the Blue Nile so as to raise the river level sufficiently to convert what would otherwise have been a very deficient summer supply into one which was sufficient for all needs.

Having indicated the geographical phenomena which characterize the Nile Basin as a whole, the peculiarities of certain portions of the river system may be examined.

On the equatorial plateau, where rain falls during the greater part of the year, vegetation grows everywhere luxuriantly, and man can, with little exertion, cultivate as much as is necessary for subsistence; streams flow in every valley, and habitations are not necessarily restricted to certain areas. Under such conditions of a moderately high temperature and plentiful precipitation, the river system does not influence the distribution of animal and vegetable life, nor the habits of the inhabitants, to the same extent that it does in more arid regions.

On leaving the plateau, however, and following the Nile northward, we soon leave behind us the protracted rainy season, and on the plains which stretch away from the foothills rain falls from May to September, while the winter half of the year is almost dry. The annual amount of precipitation, which near the foothills reaches 50 inches, decreases rapidly as we go northward, and at the mouth of the Sobat (lat. 9° 30′ N.) does not exceed 30 inches, and we find that near the Bahr el Jebel the three conditions of a warm climate, an almost level country, and a moderate rainfall, followed by a dry season lasting for six months, have caused the peculiar character of this portion of the basin. A ridge of granite and gneiss of no great height extends in a northwesterly direction from about Wadelai, and down its northern slope flow the streams which empty themselves into marshes occupying much of the low ground; to the eastward the

plains have a greater extent, and reach from the latitude of Gondokoro to the Sobat River, broken only here and there by a knoll of granite. In the rainy season these plains are flooded for miles, and the water is slowly drained off by the meandering channels which, half choked with rank vegetation, afford an inadequate escape for the water, of which a large proportion is removed by evaporation. The Bahr el Jebel, which receives a constant supply from Lake Albert, maintains an open channel and a steady flow throughout the year; many of the others, which are bank full in the summer months, soon fall as the rain diminishes, and by the winter consist for the most part of almost stagnant pools. Between these streams the country, which is largely flooded in the rains, can only be crossed with difficulty in the dry season on account of the lack of water.

The marshes of the Bahr el Jebel and the Bahr el Ghazal, though very extensive, are not so vast as they were formerly represented to be, and those of the Bahr el Jebel in particular have been much reduced by the results of recent surveys. This river flows in a very shallow valley from 5 to 15 miles wide, in which at flood time the water in the lower reaches is on a level with the surface of the flood plain, and even in the upper reaches is but little below it. The abrupt change from the steeply sloping bed above Gondokoro to the level plain below it causes most of the suspended matter to be deposited in the upper reaches, and little if any sedimentation is yet taking place in the middle and lower reaches. Consequently the sides of the flood plains are still occupied by large lagoons, which are filled in the rainy season and slowly evaporate during the other half of the year; former bends and branches of the river, which changes of the main channel have left as isolated depressions, stand full of water and furnish suitable places for the growth of papyrus and other marsh vegetation. Five hundred miles of such a marsh-grown valley can not only take the rainfall of 30 to 35 inches which falls on it, but can receive also all the water that flows out of the main stream by numerous branches and side channels; much is taken up by the dense growth of marsh plants, and the dry winds which blow from November to April off the parched plains of the Sudan rapidly carry off a vast quantity of moisture; thus it is that the trebling of the volume discharged at Gondokoro in the rainy season has no effect on the volume which leaves the river to join the White Nile at Lake No. The descriptions of the vast marshes, the rank vegetation which blocks the river bed, the difficulty of recognizing the true river channel, have given rise to an impression that the Bahr el Jebel has no defined bed, but is a shallow stream losing itself in the lagoons. But this is far from being the general case, for all the rivers of these plains excavate for themselves well-defined, steep-sided channels in which they flow. The difficulty of recogniz-

ing them is due to the fact that they flow almost at the same level as their flood plains, and, being free from suspended matter, are not building them up. Conditions are therefore favorable to the growth of marsh vegetation, which extends wherever the water reaches, and which is often able to choke the smaller channels by its growth.

In such country the inhabitants are naturally hunters and fishers or cattle owners, only a very small amount of ground near the villages being cultivated. During the rains they move with their cattle away from the rivers and marshes to higher ground between the drainage lines, and later when the wells and ponds there dry up they return to the rivers and the larger lagoons.

In the lower reaches of the Bahr el Ghazal and the Bahr el Jebel the flood plains lie lower, and the marshes are inundated for a considerable part of the year, from June to December; but this is due, not so much to the local rains as to the flood in the Sobat River. The country is here so flat that the rise of water level of 7 or 8 feet in the Sobat at flood stage raises the water level upstream for many miles in the White Nile, Bahr el Jebel, and Bahr el Ghazal rivers and in their lagoons; this facilitates the detachment from the bottom by storms of wind of the plants growing in the marshes. When once set free, these masses of vegetation drift into the main river channel, where they may be arrested at a narrow part or at a sharp bend. More masses are constantly arriving, and soon the block extends across the channel, and in time may completely close it. These sadd-blocks have occurred principally in the last hundred miles of the Bahr el Jebel immediately above Lake No, a few only having been formed near Ghaba Shambe, where the wide marshes in which the Bahr el Zaraf takes its rise cause a rise of the river level of the Bahr el Jebel in the rainy season, and so facilitate the setting free of the grass, reeds, and water plants which may then form the sadd-block. A rise of water level in the lagoons is therefore an important cause of sadd-blocks, while stormy weather and a narrow meandering river furnish the rest of the necessary conditions.

In the Bahr el Ghazal marsh region the rivers are for the most part shallower, and the vegetation which blocks them is oftener growing on the bed of the stream than drifted into it as loose material derived from the lagoons. But for all this region from Meshra el Rek to the mouth of the Sobat, there is no doubt that the flood in the latter river is the important geographical factor. Although the rains cease on the Abyssinian Plateau after September, the level of the Sobat in its lower reaches slowly rises until the end of November, and only begins to fall toward the end of December. This is due to the water which floods the plains to the south of the Sobat, through which the Pibor River flows. Miles of country are flooded to a depth of about 2 feet and are slowly drained off into the Sobat as

the supply from the plateau diminishes, so that the level in the main river is maintained. The effect of the Sobat flood is felt even as far as Meshra el Rek on the Bahr el Ghazal, for here, too, the variation of the water level follows that of the Sobat exactly in rising very slowly from June, in attaining its maximum level at the beginning of December, and in falling rapidly at the end of that month. The effect of this regimen on the discharge at Taufikia is shown in figure 1.

The Sobat, which rises on the southern portion of the Abyssinian Plateau at an altitude of some 7,000 feet, descends very rapidly to the low-lying Sudan plains, through which it flows in a well-defined channel. The slope here being low, most of the suspended material is deposited in the middle reaches, to form sand banks which render navigation difficult at the low stage. It is characterized by the late maximum level which has been already alluded to, and which notably augments the volume of water available for Egypt in January and February. In April and May its supply is small, but in favorable years it is a valuable addition to the White Nile, which may be increased by flood waves, due to occasional winter rain storms falling on the plateau.

Although the country of the Bahr el Jebel and the lower Sobat is a vast plain having a very slight inclination, the flattest portion of the Nile Valley is that between the mouth of the Sobat and Khartoum. Here, the river falls, at low stage, only 26 feet in a distance of 515 miles, or 1 in 107,000, equivalent to little more than half an inch a mile; at high stage, when the Blue Nile has risen 26 feet, the water of the White Nile is held up so that the water slope from Taufikia to Khartoum is only 11 feet in the same distance, or 1 in 255,000, which corresponds to about a quarter of an inch per mile only; but this slope occurs in the southern portion only, for from Renk to Khartoum, a distance of about 300 miles, the river presents a level surface, and this portion of the valley is a vast reservoir held up by the flood water of the Blue Nile.[a]

The river here flows through a vast plain, with the low hills of Kordofan on the west and those of the center of the Gezira on the east, which divide it from the basin of the Blue Nile. Both these hill masses consist of granites, gneisses, and other crystalline rocks, representing the worn-down stump of a hill range which in former times was of much greater importance; long-continued erosion has worn them away, and streams have distributed the material to form the alluvial plains of the White Nile. On these numberless herds of cattle and sheep are raised by the tribes which inhabit them, and in

[a] See "The longitudinal section of the Nile," Geographical Journal, July, 1908.]

some parts considerable crops are raised in the rainy season; but the rainfall rapidly diminishes as we move northward, and at Khartoum it only amounts to about 4 or 5 inches annually, which falls in the four months June to September, the remainder of the year being hot and dry. We have now left the thorn forest and the savannah type of country in which the gum acacia predominates, for north of latitude 16° even these become rare, and we enter the rainless desert of northern Africa.

At Khartoum very different conditions are encountered, not only does the rainless region begin immediately north of it, but the heavy rainfall of Abyssinia furnishes the flood of the Blue Nile which both waters the lower reaches of the river and carries down to them the red-brown silt which forms the flood plains of Egypt. The great volume of the Blue Nile flood, as compared with that of the White Nile, has already been alluded to, as well as its occurrence during a short season of four months in the summer.[a] After leaving the hills of Abyssinia the Blue Nile flows in the channel which it has eroded in the alluvial deposits which overlie the crystalline rocks of the region, and the banks are of sufficient height to prevent the flooding of the lands which border it. The slope of the river at low stage is about 1 in 3,000 between Fazogli and Roseires, but decreases to 1 in 8,000 below the latter place. It is highly probable that on the whole the river is slowly eroding its bed as the cataracts below Berber are being worn away, but the change of slope between Singa and Sennar is very remarkable. Here the slope is only 1 in 10,900, while upstream of this reach it is 1 in 8,300 and below it 1 in 9,100. Since, so far as is known, there is no ridge of hard rock at this point to account for the change of slope, a gradual warping of this part of the country may be the cause, and the extreme meandering of the parallel streams, the Rahad and the Dinder, in the same region gives some support to the hypothesis.

Below Khartoum the river enters the region of the cataracts, which are generally described as being six in number; but this is not strictly accurate, for one portion, which is but a deep and narrow gorge, is included as the sixth cataract, while, on the other hand, the important series of rapids which occur immediately downstream of Abu Hamed are ignored. At no point is there any considerable vertical fall, but each so-called "cataract" consists of one or more series of rapids, in which the water slope is from about 1 in 2,000 to 1 in 800. In every case the rock channel is formed of granite, gneiss, or crystalline schists, which have usually been greatly crushed by earth movements, in consequence of which lines of weakness have been

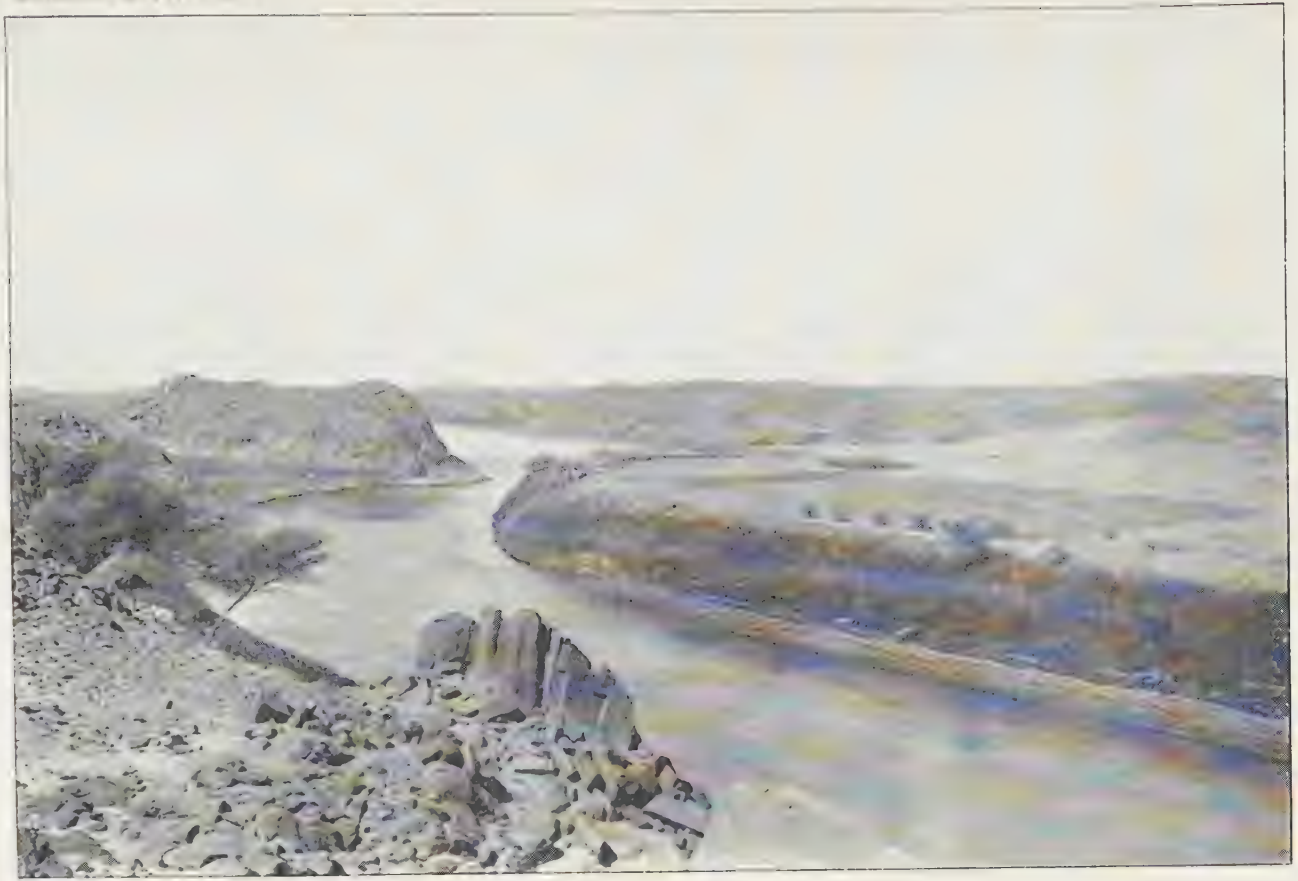
[a] Cf. Geographical Journal, September, 1906; and "Physiography of the Nile Basin," Chap. VI. Cairo, 1906.

developed, thus determining the direction of the various water channels, which often follow the line of intrusive dikes.

As the river has cut its way down through the overlying sandstone of Cretaceous age, it has met with portions of the uneven floor of crystalline rocks on which the sandstone was originally deposited, and the position of these rocky ridges has determined the position of the cataracts; but the directions and positions of the water channels, and of the different rapids, are due to the structure of the rock masses themselves as they now exist, after the crushing and dislocation to which they have been subjected during the past history of the continent.

Upstream of each of these outcrops of harder rock, which form a series of steps down which the Nile flows, there is a reach of low slope, about 5 or 6 inches per mile, in which the river flows placidly through the sandstone regions in the narrow alluvial plain which it has deposited during past centuries. These barriers of hard rock seemed to promise suitable sites on which masonry dams might be erected for the purpose of storing the additional water which was needed for the irrigation of the cultivable lands in Egypt; but a survey of the whole length of the river from Khartoum to Wadi Halfa, and the detailed examination of the three reaches which offered most prospect of storing the necessary quantity of water, showed that nowhere was there a site offering the advantages of that at the Aswan cataract, while in more than one of the sites examined the rocks had been so crushed and fissured as to afford but an unsafe foundation for large works.

Fifty miles below Khartoum the Nile, which has been flowing through a sandstone plain, enters the Shabluka gorge, which is 7½ miles long and cuts directly through the hill mass of this name. This is commonly called the "sixth cataract," but the total fall of the water level at low stage is only 28 inches in this length, and it is the rush of the whole river through a deep and narrow channel which causes the troubled water and suggests a steep slope; the depth is very great, being as much as 100 feet at one point in the middle of the gorge in January, and 80 feet at another point near the downstream end. It is very remarkable that the river should have taken its course through this isolated hill mass of crystalline rocks instead of excavating a channel through the softer gneisses which now form the low ground around. This point demands detailed investigation, but there is evidence that the gorge existed in some form at a very remote period; that it was filled with sandstone in Cretaceous times, and that in the modern erosion of the country the river has reoccupied the ancient gorge by excavating the sandstone which filled it; further examination, however, is needed before this question can be considered as finally settled.



DUMAG ISLAND, UPPER END OF FOURTH CATARACT.

A Portion of Hannek Cataract.

The next cataract, the fifth, begins about 30 miles below Berber, and consists of three or four separate groups of rapids. Together with the intervening reaches of low slope, they occupy nearly 100 miles of valley, in which the river descends 82 feet; beyond this a reach of low slope for 30 miles extends to Abu Hamed. This reach upstream of Abu Hamed seemed at first to offer many advantages for a reservoir, but a detailed survey showed that the valley opened out widely at the northern end until any economical storage of water in it became impracticable.

Here the Nile makes its great bend to the westward, flowing at times even southward; but the causes which determined this in the past have yet to be found, and careful examination of this portion of the basin is needed to lead to a solution of the problem. From Abu Hamed to Merowe, a distance of 150 miles, the river flows principally over crystalline rocks, and rapids occur frequently at short intervals. In the first 17 miles the river falls 60 feet, and afterwards follows an irregular course through these rocks for another 125 miles before reaching the head of the fourth cataract at Shirri Island, 10 miles below which is Merowe. Shirri Island was specially examined as possibly providing a site for a dam, but the valley between this point and the cataract at Abu Hamed was not large enough to contain the necessary volume of water. (See pl. 1.)

A long reach then follows, in which, for 160 miles, sandstone rock alone occurs on either side of the alluvial plain, and it is not until Abu Fatma, 40 miles north of Dongola, that the third cataract commences.

From this point to Wadi Halfa the rapids, which are collectively grouped as the third and second cataracts, occupy a great part of the river's course. In general character they have much in common with each other and with those which have been already mentioned, but each has peculiarities of its own, which, however, exceed the scope of the present paper. The erosive action of the mass of silt-laden water which pours down them in flood, and which amounts to nearly half a cubic mile of water per diem when the river is in high flood, has for many thousand years been wearing down the rocks of these rapids, and carrying the material to the delta of Egypt and to the sea. The character of these rapids may be well seen in various parts of the third cataract, and among those which occur between it and the second or Wadi Halfa cataract. At Hannek, in the third cataract (pl. 2), bands of granite traversing the gneiss, which forms the fundamental rock, give rise to obstructions to the river's flow. A point at the upper end of the Dal cataract seemed to offer certain advantages as a dam site. Here the rock is a granite, which has been highly crushed along certain lines, leaving uncrushed masses as kernels in an envelope of gneiss; the result has been to form a number of small elongated or rounded islands of granite, between which the water has eroded its

channels in the softer gneiss. (See pl. 3.) These rocks vary greatly in the resistance which they offer to erosion, and while depths of 15 and 20 feet were found at low stage in certain channels, at other points not far distant depths of 60 and 70 feet were not uncommon, and at one place a depth of as much as 130 feet was recorded. Again, at the Atiri rapids, south of Semna, an intermixture of granite and schists is the cause of the unequal erosion which has left the rocks and islands of the harder material to obstruct the fairway of the river. (See pl. 4.) At Semna, about 12 miles above the second cataract, inscriptions on the rocks appear to show that since 2000 B. C. the river has lowered its bed by about 27 feet, and recent excavations in Nubia also indicate that, since the time when predynastic man inhabited the valley, the river level has fallen, doubtless in consequence of the erosion of the Aswan cataract, while the existence of terraces of water-rolled detritus at several levels in the side valleys furnishes confirmatory evidence of this.

Throughout this region a narrow valley in a rainless climate offered little opportunity or encouragement for a population to develop and thrive. In the southern portion sufficient rain falls in the form of summer storms to enable the nomad Arab to find water and forage in the valleys sufficient for himself and his flocks, but in the northern part the country is too inhospitable for him to do more than move through it between the fertile valley of Egypt and the Sudan region of the monsoon rains, except among the hills which border the Red Sea, where water is more plentiful. Here and there in the desert are wells and in the El Kab depression, to the west of Dongola, water is found at a short distance from the surface. The origin of this water is of much interest; but as yet verified facts are so few that we are left to choose between several more or less probable hypotheses. It is, however, certain, from such measurements as have been made, that there is a considerable loss of water between Khartoum and Wadi Halfa in flood, which is greater than can be accounted for by evaporation. Much of this water makes its way into the alluvial flood plain, and it seems more than probable that it also percolates into the porous Nubian sandstone. In the rainless Nubian climate the underground water table must slope away from the river, and this water must find its way into the lower layers. In default of any accurate levels or borings in the desert, no more can be said at present, but the observations on discharge made at the Aswan dam should, when published, show what loss takes place in this manner in the Wadi Halfa-Aswan reach. It has, moreover, been shown that when the river level falls below that of the water table in the flood plain, water drains back into the river at low stage, and Mr. Craig[a]

[a] "The Nile flood and rains of the Nile Basin, 1906," Survey Dept., Cario.

THE ATIRI RAPIDS.

has shown that this may amount to as much as 3,500 cubic feet per second between Khartoum and Wadi Halfa at the lowest stage of the river. As the whole discharge is not more than six or seven times this amount at this season, it is not an unimportant factor.

The remaining portion of the Nile basin, consisting of the valley below the Aswan cataract and the delta, differs very markedly from the regions which have been referred to. A valley of rich alluvial soil, some 5 to 10 miles wide and 600 miles long, and a delta of the same character, now supports an agricultural population of exceptional density, which numbers on the average about 1,100 persons to the square mile. This tract of country possesses very marked characteristics, which have undoubtedly affected in a high degree the customs, the habits, and the character of its inhabitants. As a watered valley in the midst of an absolutely arid region, it must have been occupied in very early times, and when the remains of paleolithic man in the valleys and on the desert margins have been more fully collected and studied, it should be possible to glean important information concerning his occupation of this part of the world. At that early time the valley was probably occupied for the most part by jungle and marsh, conditions approximating somewhat to those of the Bahr el Jebel of to-day, and early man may have lived on the desert margin, fished in the river, its lagoons, and backwaters, and hunted and trapped animals in the jungle which bordered them, much as the Dinka negro does to-day. The earliest representations that we possess of the ancient inhabitants show, in their crowns, their ornaments, their ceremonial dress, and so forth, evident traces of their former occupations of hunting and fishing before they became an agricultural people. As the deposit of silt by the waters of the annual inundation continued, the banks of the river would be gradually built up, the flood plains would extend at the expense of the lagoons, and land within reach of water would become available for agriculture; and from that time onward the yearly cycle of operations, the inundation of the land by the annual flood, the sowing on the wet mud as soon as the water drained off, the harvest in the early summer months, and the period of waiting from then until the river began to fall after the next flood, repeated itself year after year and century after century without appreciable variation.

In the rainless climate of this region, weather, as we know it in northern Europe, may be said to be nonexistent—one day is almost exactly like the next and the one before it. The flood may be a little higher or a little lower than in the previous year; occasionally it may fail or be dangerously high, but in the course of centuries these slight variations are of small effect, and the conditions of life in Egypt are exceptionally constant—a water supply with a regular seasonal varia-

tion, no rainfall, a warm climate in which vegetation can grow throughout the year if the necessary water is available, a rich alluvial plain on which water channels can easily be formed; to these are to be added exceptional freedom from incursions of immigrant races of greater power or higher organization. To the east and west lie the deserts which throughout the historic period have presented a barrier which could be passed with difficulty by one or two caravan routes. To the south the Nile Valley itself presented a possible means of ingress, but one which could be closed, and was only employed to a moderate extent. The marshes of the delta restricted traffic on the north, and even the road along its eastern margin to Syria, which has been trodden by numerous armies both leaving and entering Egypt, did not offer exceptional facilities for a ready entry into the country. Under these circumstances it is not surprising to find that the Egyptians at a very early period settled down to an agricultural mode of life; that they early perfected the ordinary operations which such a life required, and, having done so, preserved them with but little change until very recent times. Simple methods were well suited to the unvarying conditions among which they lived, and there was no incentive or necessity which might compel them to modify them. This people furnishes in a very marked degree an example of an organism growing in an unvarying environment to which it had early adapted itself and its mode of life.

To the geographer such a case is especially interesting, and during recent years the archæological exploration of the country has brought to light a store of information concerning the ancient history of the Egyptians, their customs, and their mode of life which may be profitably studied in relation to their physical environment. But this is a very wide subject, and I will only draw attention to a single aspect of it which is directly connected with my own work in the country—the measurement of the land. The annual flood, rising in July within a few days of the same date year after year, and falling in October with equal regularity, has, from the earliest times, caused an invariability in the field seasons which must have reacted on the character of the people. This unvarying cycle of their water supply, of their agriculture, and consequently of their domestic life, combined with the freedom from immigration which the deserts and the delta swamps insured, laid the foundations of that conservatism of custom and character which the Egyptian has always displayed. Nor has this greatly changed, and there exists to-day in every phase of Egyptian life traits which have come down from early times almost unaltered; the examples furnished by the science of land measurement are as striking as any that we know.

As soon as any considerable tract of the country was occupied, attempts would be made to control the river and its branches, and the

natural spills and backwaters would be improved to form canals for the purpose of leading the flood waters wherever they were required; thus the water would be supplied along certain lines to the land under cultivation, and this, as well as the convenience in plowing, would quickly lead to the development of the long, narrow holding, in order that the owners of small areas should have direct access to the water channel which served them; the definition of the unit of area as being 1 cubit by 100 cubits shows this.

The geographical factors of the valley determined once and for all a state of things which the surveyor, consciously or unconsciously, had to take into account if his work was to be satisfactory, and it may be summarized as a narrow belt of country where holdings are unusually small and the land is of high value, being capable of supporting a dense population, but only in so far as the water of the Nile is readily accessible.

The method, once decided upon, would be rapidly improved and developed by constant practice, since the land had to be remeasured annually after the waters of the inundation had receded; for the whole country was at first under a more or less primitive form of basin irrigation, and only the banks of the river would be sufficiently high to be cultivated during the flood season.

As early as the first dynasty (3400 B. C.) the measures of length were in regular use, for on the Palermo stone we have the height reached each year by the Nile flood recorded in cubits and fractions of a cubit, while the stretching of the (measuring) cord at the foundation of a temple is mentioned. Every two years, a "numbering" of the royal possessions was made throughout the land by the officials of the treasury, and this would be a sort of verifying survey.

About 3000 B. C. the property of a high official, Methen, was recorded on the walls of his tomb at Saqqara as having been duly registered to him in the royal archives or registry.

Another of the tombs at Saqqara, that of a certain Mes, furnishes us with information of exceptional interest. Certain lands near Memphis, which the Pharaoh Amosis (1580 B. C.) had conferred on an ancestor of Mes named Neshi, were, during the minority of Mes, claimed by a certain Khay as his property. A lawsuit followed, in which Khay produced false title deeds, whereupon Nubnofret, the mother of Mes, appealed to the official registers, saying, "Let there be brought to me the registers from the treasury and likewise from the department of the granary of Pharaoh."

In later times, about 900 or 850 B. C., the register of the lands and springs in the oasis of Dakhla is referred to in an inscription which tells of a lawsuit concerning the ownership of a spring; nineteen years elapsed before a decision was obtained. Thus the owner's name, the area of the property, its position, and the tax due from it were regu-

larly recorded, and, in the New Empire at least, duplicate registers were kept in the treasury and the royal granary. Boundaries were described as north, south, east, and west, without being any more exactly defined, just as in the Egyptian title deeds of to-day, and the Nile, the desert, or the land of such and such a landowner were recorded as being situated on the confines of the plot referred to. A nomarch of Assiut, about 2300 B. C., says that he irrigated by a new canal the highland which otherwise could not be cultivated. The Vizier Rekhmara, in his tomb at Thebes, records how cases of disputed ownership in land were to be dealt with, and all approved titles registered, but unregistered claims were ignored.

At El Kab, in the tomb of Sebek-nekt, land is divided into low-lying, of which there were twenty "thousands," and land on the high ground (one hundred and twenty "thousands"): the unit which the sign for "thousand" represents is 10 arouræ, or about 6.3 acres.

At every period, therefore, of ancient Egyptian history, the land was measured and recorded with considerable accuracy; property was dealt in regularly, and an elaborate system of registration was maintained. No map of landed property in ancient Egypt has come down to us, but on the tomb walls we meet with representations of land measurers at work. Their methods of land measurement are represented on the walls of the tomb of one Menna at Sheikh Abd el Qurna, in Thebes, a land overseer and inspector of the boundary stones of Amon. The scene depicted shows two chain men measuring a field of corn with a long cord, on which are knots or marks at intervals which seem to be about 4 or 5 cubits in length; each also carries a spare cord coiled up on his arm. Beside them walk three officials, who carry writing materials, and who are accompanied by a small boy carrying writing materials and a bag in which are probably documents and plans referring to the property. An old man and two boys also accompany the surveyors, and a peasant brings a loaf of bread and a bunch of green corn.

A similar scene is pictured on the walls of a tomb belonging to a certain Amenhotep, also at Sheikh Abd el Qurna. Here only one man accompanies the chain men, each of whom, as usual, carries a spare cord. The figures are larger than in the tomb of Menna, and though they are now much damaged, it is possible to see clearly that the cord terminated in a ram's head.

The statue of the priest Pa-en-anhor from Abydos, and now in the Cairo Museum (Cat. No. 4875), shows him in a kneeling position and holding a rolled-up measuring cord, at the end of which is a ram's head.

Of their topographical maps two alone have come down to us drawn on papyrus. One of these, which is only partially preserved, represents the mining district east of Quft, and dates from the time

EGYPTIAN LAND MEASURERS THEBES.

of Rameses II; the other is probably a plan of one of the mining centers lying farther to the south. Two valleys run parallel to each other between the mountains, one of them being covered with blocks of stone and bushes, while a winding valley unites them. One valley and a narrow pass are said to lead to the sea; the name of the place which is reached by following the other valley is not decipherable. Other features in the map are the mountains in which gold is found, and others where it is worked; a sanctuary of Amon, as well as miners' houses and a water tank or well, around which is shown a patch of cultivation, are indicated.

Of accurate measurements on the ground we have numerous examples in the pyramids, temples, and rock tombs; the pyramids of Giza furnish perhaps the best known and most fully studied instances.

Not only were the Egyptians of these remote times competent to measure lands and lay out large buildings, but they had attained a very satisfactory accuracy in leveling, and of this the pyramids of Giza again furnish proof. Borchardt, in his paper on "Nilmesser und Nilstandsmarken,"[a] adduces many facts in support of the view that they carried out a line of leveling from the head of the delta to the first cataract in connection with the nilometers which were built at every important town; and this, too, was done with a very fair accuracy, since the average slope from the scales on these nilometers works out at 1 in 14,440 against 1 in 13,700, as given to-day by the levels of the irrigation service. The instrument used was a right-angled isosceles triangle of wood, with a plumb line attached to the apex; it was doubtless used on a long wooden straight edge, which, in its turn, rested on pickets. In this way leveling of a very fair accuracy could be rapidly executed.

The principal unit of length from the earliest times was the cubit of 20.6 inches, containing 7 palms or 28 fingers, which was called the royal cubit, distinguishing it from the short cubit of 6 palms.

For land, a measure of 100 royal cubits, named "khet" or "khet-n-nuh," "a reel of cord," formed the unit, while the usual itinerary measure was the ater, or schœnus.

The areas of the fields were reckoned in squares of the khet, or 100 royal cubits, such a square being called in Egyptian "set," and in Greek "aroura." It was considered as being composed of 100 strips, each 100 cubits long by 1 cubit in breadth. The divisions of the set or aroura were the half, the quarter, and the eighth, after which the cubit became the unit; but in late Ptolemaic times the subdivisions were continued to the thirty-second, and the Greeks carried them further, to the sixty-fourth part. A half aroura was also in use in late Egyptian times, and this exemplifies the approximate methods

[a] Abhandlungen d. königl. preuss. Akademie, Berlin, 1906.

used in computation, for it was called "remen," or the upper arm. This was a measure of 5 palms, whereas the royal cubit contained 7 palms, so that their squares contained 25 and 49 square palms, respectively, or a proportion of nearly 1 to 2. At Aneiba, a village nearly opposite Ibrim in Nubia, there are some tombs in which the extent of certain estates is represented by notched rectangles. Each subdivision thus formed represented, doubtless, a set or aroura. Small areas, such as a well or tank, were given in square cubits.

Thus, the units in use in ancient times for land measurement were:

Length:

Royal cubit, equals	20.6 inches.
Khet (100 cubits), equals	57.2 yards.

Area:

Square cubit, equals	0.305 square yard.
Cubit of land (100 square cubits), equals	30.5 square yards.
Set or aroura (100 cubits of land), equals	3,050 square yards.
The "thousand," or 10 arouræ, equals	6.3 acres.

In Roman times, we have several additional units, which are given in a papyrus (No. 669) found at Oxyrhynchus (Bahnessa) in 1903, by Professor Grenfell and Doctor Hunt, and which dates from about 290 A. D.:

2	palms make a λιχάς.
3	palms make a σπιθαμή.
4	palms make a πούς.
5	palms make a cloth-weaver's cubit.
6	palms make a public and a carpenter's cubit.
7	palms make a nilometer or royal cubit.
10	palms make a βῆμα, or the distance of the outstretched feet.
3	cubits make a public ξύλον.
4	cubits make an ὀργυιά.
?	cubits make a κάλαμος.
6⅔	cubits make an ἄκαινα.
40	cubits make an ἄμμα.
96	cubits make a schœnium of land surveying.
100	cubits make a schœnium.

The schœnium, like the khet in earlier times, was the side of the square aroura or set, and measured 100 royal cubits of 20.6 inches; and the aroura contained about 3,050 square yards, or five-eighths of an acre. But the papyrus just quoted says that schœnium used in land surveying was a square of 96 cubits; one probable reason for the change being the greater convenience in estimating the thirty-second and other fractions of the aroura.

But these measurements are not those which are in use to-day. Though the ancient measure of the aroura is referred to in papyri as late as the sixth and seventh centuries, in an Arabic papyrus from the Fayum, dated 724 A. D., the feddan is used to define areas. It is very remarkable that the older measures, which had been so long in use,

should have been within a hundred years, or rather more, completely replaced by one of Syrian origin, which has remained in use ever since.

But little is known of the manner in which land was classified in ancient Egypt, but papyri, of Ptolemaic age, from the Fayum give full details of the system which then existed. There was very little difference between it and the present-day practice. Private land was classed separately from that of the government; canals and canal banks were shown; land which had deteriorated was transferred from one class to another; in fact, the measurement and registration of land two thousand years ago differed but little from the present practice, except that the methods of computation were approximate instead of being exact; but even this change is limited to the present survey, and has not yet become the universal practice.

In early historic times Egypt was largely agricultural, but a great extent of marsh and lagoon still remained which was flooded annually, and retained water to a greater or less extent throughout the year. As time went on man controlled more and more the flood waters, and extended his cultivation as the marshes were silted up or drained. When the whole of the flood plain was under cultivation, as well as the greater part of the delta, the annual flood was of paramount importance, and the extent to which its waters could be led determined the maximum area which could be cultivated. Now modern engineering science has supplied water at all seasons of the year to both the valley and the delta, so that the flood has lost its importance, and the low-stage supply of the river has become the first consideration, so much so that heavy expenditure is incurred to augment it in every possible way; the natural resources of the country have been immensely increased by fully utilizing a climate which favored the growth of vegetation throughout the year if water was obtainable.

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HEREDITY, AND THE ORIGIN OF SPECIES.[a]

[With 1 plate.]

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The surface of the earth is inhabited to-day by hundreds of thousands of forms of life, which upon analysis are found to be separable into groups or species, with well-marked and characteristic attributes, which may be transmitted from generation to generation. The strata beneath the surface are found to contain the remains of thousands of other forms now extinct, but which show certain general relationships to the existing organisms. If we piece together the actual records and take the backward bearing of our information, we arrive at a period sometime within the last six hundred thousand centuries, when living matter was more indeterminate in the forms which it assumed, and was, perhaps, quite unlike any protoplasm we meet at the present time.

From this primitive substance series of organisms have been produced, which, in the successive stages of the earth's history, show an increasing complexity as the present epoch is approached, and which embrace more numerous forms with the advance of time.

In this upward movement, this evolution from the simple to the complex, in the production of many from few, it is not to be taken for granted that protoplasm has been a perfect automaton, and that it has nothing but successes scored to its credit in the ever-changing conditions it has met since its beginning. On the contrary, the succession of its forms is a most devious one, and by no means easily traced. Phylogenetic systems are made up chiefly of allowable suppositions, and it is altogether probable that we do not know more than a fraction of the course of the zigzag, halting, and at times receding steps followed by living matter in its development into existing types.

Thus the mosses are seen to have reached the ultimate development allowable by their morphological character, and hence are incapable

[a] Lecture delivered before the Barnard Botanical Club, Columbia University, December 18, 1905. From The Monist for January, 1906. Reprinted by permission of the Open Court Publishing Company, with corrections by the author.

of any movement which will produce higher or better organized types. Accordingly we may assume that their existence as a constituent of the flora seems to be doomed to a diminishing importance, if not final extinction. The fernlike plants are also examples of a great phylum of the vegetable kingdom which, in the Carboniferous period, being most suitable for the conditions present, constituted the prevailing type of vegetation, making up perhaps as much as three-fourths of the plant covering of the land. Their organization is one which promises nothing of advantage vegetatively and reproductively, and we are now at a time when we see them slowly but inexorably being supplanted by seed-producing forms.

Of the hypotheses that may be taken more seriously, one that has even lately been regarded with much favor, predicates that organisms undergo transformations, or alterations by adaptive changes in their organs and entailed functions, as a direct reaction to environmental factors, and the altered features becoming fixed and inheritable, the organism receives a lasting imprint from its habitat. Migration to new areas or changed climatic conditions might give opportunity for new stimuli and different reactions which might, or might not, affect those previously made. We need not at this time go into the intricacies of the arguments that cluster about this main thesis or weigh the evidence that is drawn from the presence of useless, vestigial, and useful characters in various organisms.

Popular belief in the influence of environment and the inheritance of acquired characters finds its commonest expression in "that plants have been changed by cultivation." Domesticated races are spoken of as "garden forms" by botanists and horticulturists, with the implication that they are specialized types resulting from the effects of tillage. Now, so far as actual cultivation is concerned, this assumption is without foundation, since at the present time no evidence exist to show that the farm, garden, or nursery has ever produced alterations which were strictly and continuously inheritable, or were present, except under environic conditions similar to those by which the alterations were produced, although vague statements and erroneous generalizations to the contrary are current. It is true, of course, that structural and physiological changes may be induced in a strain of plants in any generation, which may persist in a share to the second, or even in some degree to a third, but no longer. Some very important operations of the market gardener and the farmer are dependent upon this fact.

The possibility that permanent changes might be induced is by no means to be denied, and it is a fair subject for investigation. Actual evidence is to be obtained only by observations of breadth under guarded conditions. Until this is at hand all affirmative conclusions can be but inferential and suggestive.

Vicinism, the somatic multiplication of bud sports and extreme variants from a fluctuating series, and the confusion of closely related elementary species form the basis for the greater number of mistaken assertions as to the effects of cultivation. It is obviously necessary to examine all facts bearing upon the lineage of supposedly new forms, with the greatest care before their aspect, or behavior may be taken as evidence upon phylogenetic problems.

The theory of natural selection of an intraspecific application, as one of which new forms might arise, is so well known that we need not particularize in defining its ramifications. Briefly, it is assumed that, as the whole mass of individuals comprised in a species is in a constant state of variation, the individuals which show features even the most slightly better adapted to the environment survive, while the less fit perish. Thus by infinitely small changes during each generation a species moves away from the ancestral type in one or more directions until in the course of thousands of years the differences become so great as to be appreciable, and of a specific character, to use an arbitrary phrase. Three insurmountable objections to the acceptance of this method as universal present themselves. First, the fluctuations exhibited by the individuals comprised in a species do not in any known instance transgress definite measurable limits, and do not depart from an ascertainable norm or average; secondly, the gradual transition of individuals from one type to another, that is, intergrading forms, demanded by this theory, are not found among plants; and, thirdly, although we have preserved specimens and records of several species which cover their history for many thousands of years, yet such gradual transformations are not observable. Lastly, it is to be said that it is extremely doubtful if the earth is old enough to have permitted the development of the great number of organisms which inhabit it by this method.

A secondary idea that has been formulated in connection with this subject is that of orthogenesis, by which the organism evolves rudimentary structures purely as a result of internal forces, and initially without reference to utility or to environment. These rudimentary organs may, in the course of generations, wax in size, undergo increasing differentiation of structure, perhaps finally becoming subfunctional, or even fully functional, although nascent organs are not always supposed to attain this useful end. In support of this theory it has been pointed out that plants and animals show many structures which, so far as our understanding of them goes, are wholly without part in the life of the organism. The present development of plant morphology, however, is one which is carrying us farther and farther away from the conception of such prefunctional formation of organs, as the whole tendency of modern investigation is to place the morphogenic processes upon a physiological basis. On the other hand, the

argument that the variations of the organisms are "determinate," and are governed by the morphological possibilities, is one which surely holds for any method of phylogenetic procedure. Thus it needs but the briefest common-sense consideration to show that any given type of leaf or flower could not possibly vary toward all other types, but only in the direction of certain forms not too widely different.

A more explicit statement may prevent a misconception. It has been held by some writers that variations and mutations theoretically follow those already made, as a projection of them, or a continuation, which carries the organs concerned successively and ever nearer some ideal form or type. This is determinate variation in its strictest sense. On the other hand, it is argued that from any given stage in its development an organ may vary or mutate in any direction, limited, of course, by its morphological possibilities, and such alteration may lead the structures concerned in any given course from that previously pursued. It need only be said that to the experimenter the latter view seems to be the more fully justifiable by the facts observed in mutations.

First, it has been known for over half a century that fixed forms, constant in inheritance and self-maintenant, therefore constituting species, have resulted from hybridization. The fertilization of the egg cell of one species by the pollen of another often results in an interlocked and stable combination of the characters of the parental forms in such manner as to give rise to a new type unlike either of the parents, variously intermediate and constant to the new type in succeeding generations. More than a thousand such fixed hybrids, or hybrid species, are known, some of which have been formed anew experimentally and are thus beyond doubt. It is to be seen therefore that hybridization has played, and is playing, no small part in the composition of the flora of the earth, and that it must be considered as an active, and not unimportant, factor in the evolution of plants.

The second method by which new characters and new species have been seen to arise in the succession of generations in plants is that of discontinuous variation, or mutation. In following out the germination of hundreds of seeds in pedigreed strains of plants, a few individuals may be found in each generation which are notably different from the type in anatomical and physiological features. These divergencies are variously heritable, constituting breaks in descent, by which, in some cases, new species originate. Such seed sports or seed mutants have been seen hundreds, perhaps thousands, of times during the last two centuries, but it is only within the last twenty years that their phylogenetic importance began to be appreciated. It will be of interest to this assembly to know that American botanists

and horticulturists have made early observations of direct interest in this connection. Thus Dr. Arthur Hollick, while a student at Columbia University in 1879, said in writing of white varieties of colored plants:

> First, then, we have to consider those sports of nature where there has been a sudden change, without any intermediate steps, from a plant with colored flowers to a pure white variety; such may be termed "negative" varieties, since their peculiarity is due rather to an absence of color than to the presence of white. Not only does the flower show the characteristic absence of color, but the leaves, stem, and, in fact, the entire plant, are invariably of a lighter green; and if any red be normal to the stem (which is often the case) this will also be of a lighter shade. It has often been urged that these albinos are mere "sports" of nature with nothing constant about them * * * and that there is nothing inherent in the constitution of the plant. Fortunately, I have been able to test this * * * and found them * * * not only constant in their peculiarities, but also that these are bred in the plant and capable of inheritance.

Three years later, about the time that De Vries began casting about to find material suitable for the demonstration of his theory of unit-characters and their saltatory action, Mr. Thomas Meehan, a horticulturist of Philadelphia, wrote as follows in a discussion of some anomalous form of the oak:

> The conclusion that I have been forced to is that the odd forms we often find in nature are not necessarily hybrids, but are as likely, if not more likely, to be the outgrowth of some internal law of form with which we are as yet unacquainted. That they do not often perpetuate themselves is [not, plainly implied] remarkable when we remember that of thousands of seeds produced on any one tree but a very small percentage ever gets a chance to form, and of those which do sprout, again but a small percentage survives to become bearing trees. As the number of trees reproducing the general features of the original may be as a hundred to one of the more strikingly aberrant forms, we may see that though individual instances may be common, we are never likely to meet many trees of one stamp. Once in a while an individual tree may find itself in a situation favorable to the preservation of a number of seedlings, which might endure until again reproductive; in such cases a marked variety may originate and make its way over the earth.
>
> I have often thought it probable that in time a few individuals of these suddenly introduced forms might again leap into new features, and then, if they should be able to sustain themselves, we should have new species quite independently of any principle of natural selection; that principle, as I understand it, being governed chiefly by "environment."

These utterances may be taken as prophetic in part, and in part as a natural expression of the inadequacy of explanations of the origin of species current at the time. Shortly afterwards, Professor de Vries, impressed with the necessity for obtaining positive evidence upon the subject, began an examination of the plants in the vicinity of Amsterdam, Holland. Over a hundred species were brought into cultivation and tested by guarded pedigree cultures, and every pre-

caution was taken to exclude interference of agencies which might introduce errors. It is impossible to describe the enormous amount of work entailed in such investigations, but the truly splendid results

FIG. 1.—*Oenothera Lamarckiana*, the parental form which is giving off many mutants. A, B, and C, leaves from rosette; D, leaf from middle of flowering stem; E, bract; F, flower with petals removed; G, petal.

well justify the tedious care by which lines of descent were carried through successive generations for two decades without allowing a trace of doubt as to the purity of the lineage involved.

During the last four years a partial duplication and an extension of these experiments has been carried on in New York. It seems unnecessary at this late date to go into the detail of the mutations of Lamarck's evening primrose, especially since the phenomena exhibited

FIG. 2.—*Oenothera rubrinervis*, one of the mutants of *O. Lamarckiana*. A, B, and C, leaves from rosette; D, leaf from middle of flowering stem; F, flower with petals removed; G, petal.

by them are also to be seen in many other species. By way of illustration it need only be said that this plant, as originally observed by De Vries, was found to give from two to five plantlets in every hundred which were widely divergent from the type, and could, upon

maturity, be arranged in several groups, and in fact constituted several possible species. One, *scintillans*, was eversporting, and continuously and consistently gave rise to a variety of forms in its progeny, which included the parent and its mutants. Another, *lata*,

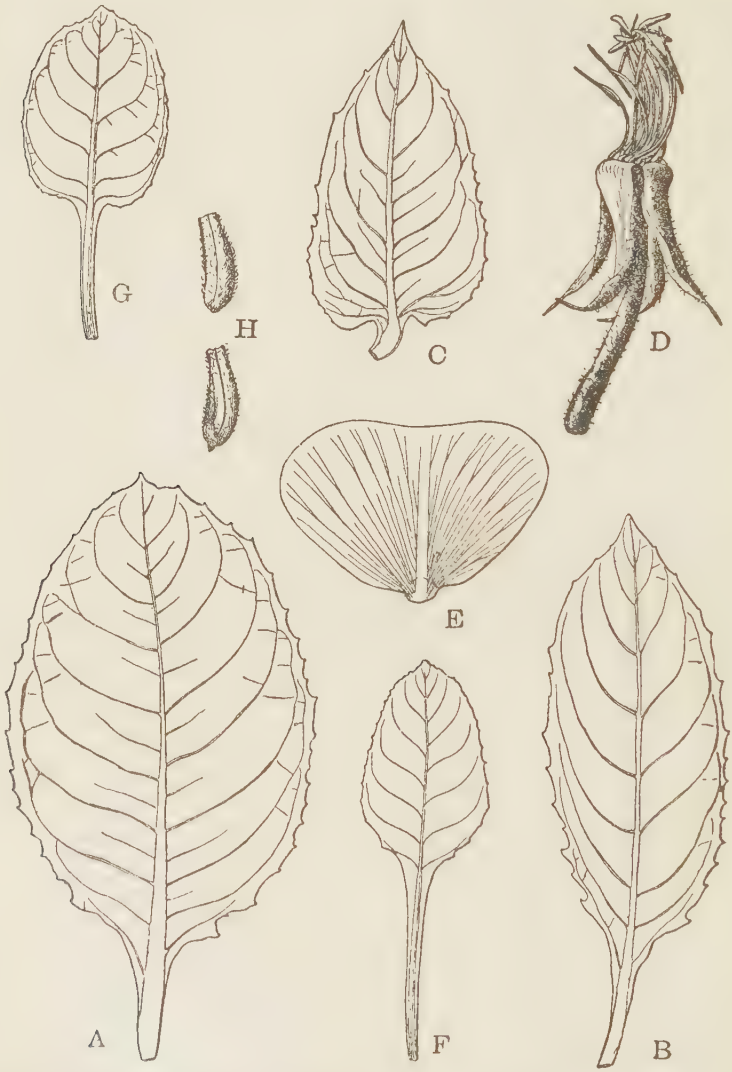


FIG. 3.—*Oenothera gigas*, one of the mutants of *O. Lamarckiana*. A and B, leaves from middle of main stem; C, bract; D, flower with petals removed; E, petal; F and G, leaves from the rosette; H, capsules.

was imperfect and did not mature pollen, and hence was incapable of independent existence. Others were perfect and vigorous, both vegetatively and reproductively, and have been found capable of sustaining competition with the parental type. Of these, *rubrinervis* grows

more rapidly, germinates its seed more quickly, and makes more numerous branches, and bids fair to be able to win out in a struggle with the parent in all of the phases of the struggle. *Gigas* is a more vigorous form than the parent, and both it and *rubrinervis* show a tendency to predominate when crossed with the parent. *Brevistylis* was found in the original location from which the mutating strain was taken, and as it has not appeared in any of the pedigreed cultures of the parent type in twenty years and still maintains itself in the original locality, it may be designated as a mutant which not only has arrived, but has survived under perfectly natural conditions. Recent cultures in the New York Botanical Garden from seeds of Lamarck's evening primrose, sent from various parts of the world where the species is under cultivation, demonstrate that it is not alone the plants observed by De Vries at Hilversum that are mutating, but the same derivatives are being given off in widely separated localities.

The evening primrose of the Adirondacks and northern New England, *Oenothera cruciata*, has been found to give atypic individuals conforming to a single type, which is also represented by specimens that have been collected in a wild state; so that here, also, we have the survival of a species which is still arriving in a large proportion of the progeny. The great-flowered evening primrose, *Oenothera grandiflora*, of the Southern States has been grown during two generations and it also is found to give derivatives, one or more of which appear to be already represented in the flora of the region.

One of the most interesting correlations to be made from a study of the results of these observations is to be found in the parallel mutations exhibited by the several species, in apparent contradiction of the principle of radiate variation and mutation (*allseitige Mutationen*). Among these are to be mentioned the origination of a form with cruciate flowers of the same general form as the *Oenothera cruciata* of the Adirondacks, from the species known as *O. biennis* in Holland, which is not identical with any species known to grow wild in America. The same species has also been seen to give off a mutant having the character corresponding to the mutant *nanella*, coming from *Lamarckiana*, according to De Vries. Then an evening primrose of unknown identity has been found on Long Island by Doctor Shull, far removed from the locality inhabited by any other cruciate plant, and strongly suggestive of a mutation from *biennis* or some other form native to that locality. Such facts merely show that the forms borne by nearly related species lie well within the limits of the morphological possibilities in saltations and that they may be expected to be duplicated in other observations.

Scattered through the literature of botany and horticulture of the last century are scores of records of the sudden appearance of sports

and forms of the aspect of species which fully support all of the conclusions drawn from the observations on the evening primroses. An examination of the facts easily brought together allows us to see that certain general principles in the organization of the plant and in its behavior in these breaks or saltations in heredity may be made out.

The first and most important of these is one which was advanced by De Vries speculatively before he began his experiments in heredity, namely, that the plant is essentially a complex group of indivisible unit characters. These unit characters may not always be expressed, or recognizable in external anatomical characters, since they may be in a latent condition, or totally inactive, or external taxonomic characters may really consist of several elementary qualities, but these are not shown in any intermediate stage, although they may be modified within the limits of fluctuating variability.

Any plant, supposedly, includes thousands of unit characters, and as they are essentially qualities, or capacities, they do not usually coincide with the characters ordinarily used in taxonomic descriptions. As an illustration, the phases of geotropic sensibility of an organ may be considered as a unit character. Thus a branch is either apogeotropic, directing its tip directly upward, or it may be diageotropic placing its axis in a horizontal plane, at right angles to the action of gravitation, or it may undergo a mutation and "weep" or direct its tips directly downward. In any case, however, it possesses one of these three forms of reaction. It does not follow, however, that all branches are actually in one of these three positions, for other forces to which it reacts may operate to place the axes in various planes, and the position of the branch may express just such concurrence of elementary characters as alluded to above, or, indeed, the geotropic unit character may be latent, and the organ may respond to other forces exclusively. Similar analyses must be used in the delineation of all unit characters, and it is obvious, without further discussion, that we will never be able to uncover, either theoretically or actually, more than a few of these indivisible units. The forms and activities by which we recognize plants must by no means be taken to be simple in their constitution unless proved to be so, and the modification of a character in hybridization and otherwise must be taken as proof that it is not an elementary feature.

In tracing the development of species it is found practicable to designate them as retrogressive when a distinct unit capacity or unit character is lost or, rather, becomes latent. Thus the loss of color must be of this kind, and also the loss of geotropic reaction, while the power of forming laciniate leaves when shown by mutants from a simple-leaved type would be estimated as a progressive mutation, as the group of characters concerned belong to a more highly organ-

ized type of organ. If a white-flowered species should give rise to a form with colored flowers, it might well be taken as a degressive movement, or as a retracing of a step once lost, since all flowers were in all probability originally colored. Here again the actual test is hybridization, it being accepted that the retrogressive forms of organs are recessive or latent when crossed with the parental or nearly related types.

As to latency we can only say that strains of plants do carry capacities of one kind and another for many generations without these particular forms of unit characters showing any activity. Thus a mutant which springs from a parental type and shows a laciniate leaf instead of the ancestral leaf must carry the latter form in a latent condition. The latent character may be awakened from time to time, or may be entirely and permanently inactive. The most easily analyzable examples of latency are seen in hybrids. Thus when the blue-flowered *Veronica longifolia* was crossed with a white-flowered variety derived from it, the progeny was entirely and continuously blue flowered, except for occasional bud sports. The white-flowered condition was here very evidently in a latent condition. In other instances white-flowered forms have appeared as a recessive, forming one-fourth of the progeny. If qualities have a cytological basis, and we may certainly assume that they do, then it is not easy to speculate intelligently on the probable condition of latent characters.

A very striking feature of mutants consists in the fact that the gross anatomical characters in which they diverge from the parent shows a much wider range of variability around its new norm than does the homologous character in the parental type. Many observations bearing this interpretation have been on record for sometime. Charles Darwin, in his Origin of Species, noted that varieties varied more widely than the closely related species from which they were supposed to be derived, and many other observers have touched in one way or another upon the subject. Doctor Shull's recent researches upon this subject led him into the making of exact measurements, by which he also finds that the wide fluctuations of the mutant characters are accompanied by a lesser degree of correlation than prevails in the parental forms. Thus, for instance, the leaves of *rubricalis* not only vary relatively more in width than those of the parental *Lamarckiana*, but the proportion between the width and length is not so constant as in the latter. Other organs of these and other species were subjected to exact measurements with similar results, while a large number of recent observations are known which justify the conclusions just stated. Of these, the great variation of the length of the pistil in *brevistylis* in comparison, and the wide fluctuations in laciniate leaves are good examples. Many of the latter

are known to be direct derivatives of simple-leaved ancestors, and are therefore capable of easy observation. With these facts in hand the possibility suggests itself that we might be able to distinguish between a structure recently arisen and one which was borne by a related species for thousands of years, but the exactness of such estimates is a matter of conjecture.

FIG. 4. Range of variation of the ratio of width to length of leaves in the parental *Lamarckiana* and one of its mutants. The dotted line shows that the range in the parent is 28–53, with a coefficient of variability of 9.53±0.22 per cent, while in the mutant represented by the solid line the range is 20–48, with a coefficient of variability of 10.30±0.22 per cent.

It seems to be taken for granted by a great number of workers interested in this subject that species showing wide variations of the organs are the ones most likely to offer a high frequency of mutations, and my correspondents in various parts of the country are constantly calling attention to these forms under such a mistaken impression. As a matter of fact we may confidently expect that the species which show the greatest variation, or are ever sporting, are the youngest.

Now, having obtained the result just described, we find ourselves face to face with one of the most interesting and difficult questions in heredity. If the newly arisen mutant forms are more widely variable than the older ones, how do they ultimately become narrowed? If the greater number of species originated by mutation, as we

confidently believe they did, then they must have shown a much wider range of variability than they do at present. By the operation of what agency has variability been decreased and correlations made more strict? At the present time I am compelled to say that I can not make an intelligent suggestion. Again, if new characters vary widely at first, and lose this power, would it be possible to estimate the age of any given character of a species from the degree of variability? The author of the investigations just noted suggests that the best prospect for evidence of value upon this point might be obtained by a comparative statistical study of more recent types of structures in the foliar or reproductive organs, and of older forms that have come down from the previous epoch. It certainly offers a most alluring field for research, and will doubtless soon receive attention.

Let us return to the question of the diversity of mutations which may ensue in any species. Theoretically a plant might show discontinuous variation in almost any direction, but this departure of course does not exceed an amplitude determined by the morphological possibilities. With all of these features taken into consideration, however, it is to be seen that it might be possible for any plant in a mutable condition to give rise to dozens, or perhaps scores, of types simultaneously, while on the other hand it may originate but one aberrant form at a time. Lamarck's evening primrose is producing a dozen, and the common species but one or possibly two, while the great-flowered species is throwing off three or four, as far as our observations go. It will be profitable to analyze the consequences of the origination of diverse types simultaneously. In the case of *Oenothera grandiflora* it ranges from Kentucky southward to the Gulf over climatic and edaphic conditions of wide diversity. If it be assumed that all of the mutants are being given off by the whole species, then these must be thrown into the struggle for existence under conditions widely different. In some cases one mutant finds itself equipped to survive in the given environment, and it does so in competition with the native flora, including the parental form. In a different part of the natural range of the parental form a second mutant might have the advantage, and it alone of the entire brood would survive, while a third would be the best form for still another set of conditions. So well in accord with the facts do we find this assertion that it is not hazardous to predict that when a final survey of the distribution of *Oenothera grandiflora* and its mutants is made some such arrangement will be found. With this idea we must also concede that many of the mutants, so far as our experience goes, do not meet at all the conditions suitable for their existence, and these perish. In brief, we have natural selection, not a selection within species, but a selection among species, by which certain ones are

elected for survival and others doomed to destruction no matter how numerously or how long they may be thrown off by the parental type.

As to the periodicity of mutations our information is not very extensive. Does a species, as it produces generation after generation in the course of centuries, arrive at a point where it begins to give off atypic individuals, and is this process continued for a time and then discontinued? We can only say that we find some species mutating and others not; we have not seen either the opening or closing of the mutative period in any species. This consideration is com-

		X_2	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9		
			50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140		
			55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	145		
X_1																							
−12	17					1																1	
−11	18			1																		1	
−10	19																					0	
−9	20			1		1	3	1														6	
−8	21		1					1			1											3	
−7	22				1	2																3	
−6	23						2	2	7	2		1										14	
−5	24						1	2	6	2	1	2			1							15	
−4	25						3	2	6	6	3	5	2			1						28	
−3	26							3	5	6	11	3		1	2	1	1	1				34	
−2	27							2	15	11	7	9	6	3	3				1			57	
−1	28							3	4	10	8	16	5	9	1	2						58	
0	29							1	2	11	19	10	3	6	5	1						58	
1	30								1	13	12	10	16	10	8	1	2		1		1	75	
2	31				1					2	11	18	21	6	3	1	1	1	1			66	
3	32									1	8	17	20	8	7	3	3	1				68	
4	33										1	9	9	7	6	3	2					37	
5	34											1	6	15	5	7	1	2				37	
6	35										2	3	4	13	5	2	1					30	
7	36											1		1	3							5	
8	37										1	1		1	2	1	2					8	
9	38														2		1	2				5	
10	39														2	1	1					4	
11	40																1					1	
			1	2	2	4	9	17	46	64	85	106	92	80	55	24	16	7	3	0	1	614	

FIG. 5.—Correlation table of length and width of leaf in *O. rubrinervis*. (p=0.6604±0.0119.) (After Shull.)

plicated, however, with that of the frequency of the mutants. Thus in Lamarck's evening primrose five in every hundred plants are mutants, and it is conceivable that the atypic form might not occur more than once in a thousand, or once in ten thousand, or once in a million. These large numbers of plants of any species are not all in existence at any one time, and it might take years, or even decades, to bring one mutant within the range of the possible number, in which case a false conception of the mutative period might be gained. It is suggested, therefore, that the conception of frequency of mutation is

the primary idea, although the action might become intensified in certain periods of more or less definite limits.

Finally we may consider the causes inducing or affecting mutations. Mutants are found to be the most numerous under conditions most favorable to the growth and reproduction of the parental type, and this is also true of all anomalous structures. It is thus to be seen that mutations probably do not give rise to species most readily under the stress of unfavorable environment, or under any conditions

		X_2	−9	−8	−7	−6	−5	−4	−3	−2	−1	0	1	2	3	4	5	6	7	8	9	
			45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	
			50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	
X_1																						
+13	24		1					1														2
+12	25				1																	1
+11	26			1	1																	2
+10	27					1	1		1													3
−9	28					1	1		1		1											4
−8	29						1	2	3	2	1											9
−7	30						1	2	2	2	3											10
−6	31							1			2	2										5
−5	32								2	2	4		2									10
−4	33						1	1	6	3	4	4	3									22
−3	34							1	1	5	8	3	3	1								22
−2	35							1	2	4	9	6	1	4	3	1		1				32
−1	36						1	1	1	2	5	10	4	5	1		1					31
0	37							1		3	11	9	11	8	5	3	1					52
1	38							1		4	3	11	10	16	3	1						49
2	39										3	7	7	8	4	1	1					31
3	40										6	4	9	6	12	3	4					44
4	41											1	8	10	5	5	1	4	1			35
5	42											2	7	9	5	3	2	1			1	30
6	43									1			1	8	4	2	2				1	19
7	44													3		6		2		1		12
8	45													1	1	1	1	2				6
9	46															1						1
10	47																				1	1
11	48																2				1	3
12	49													1					1			2
13	50												1									1
			1	1	2	2	6	12	19	28	60	59	67	80	43	27	15	10	2	1	4	439

FIG. 6.—Correlation table of length and width of leaf in *O. Lamarckiana*. (p=0.7916±0.0090.) (After Shull.)

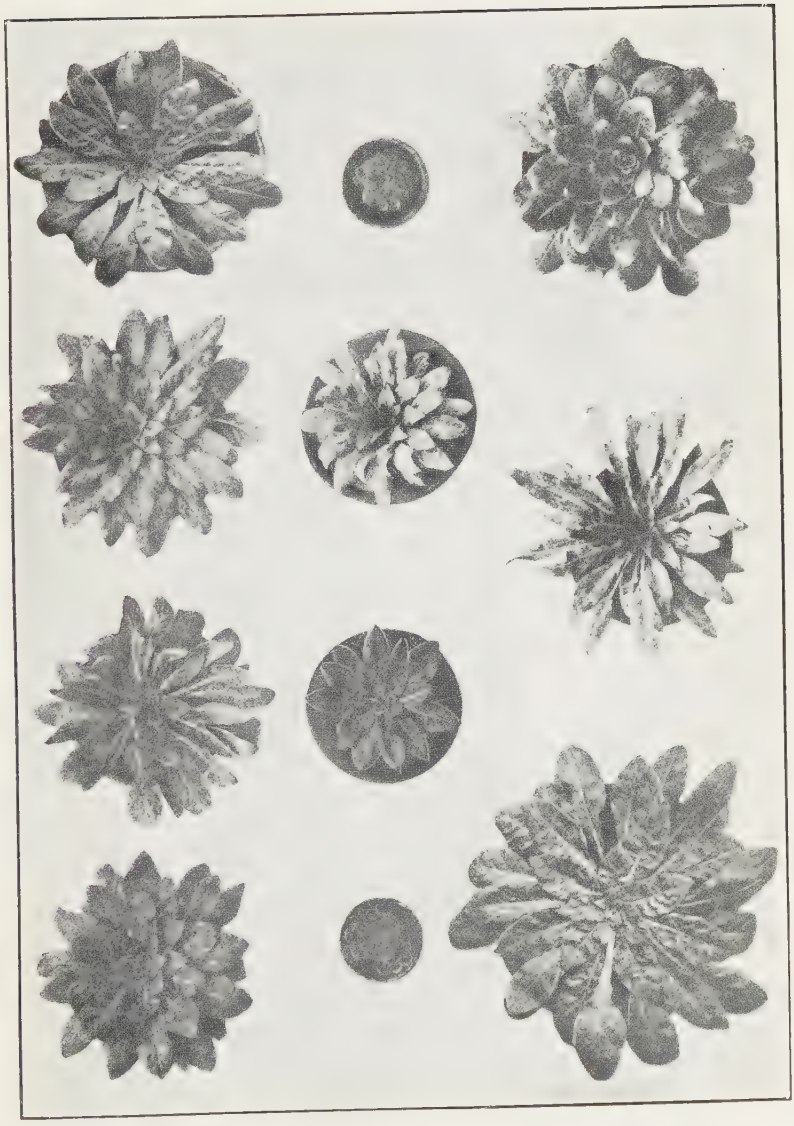
which weaken the parental form, but when it is at a maximum of activity.

In the attempts to localize the changes in the cells, or in the chronosomes, which result in the formation of atypic individuals from seeds, we are confident for theoretical reasons that these ensue previous to the reducing or qualitative divisions in the formation of the egg, or in the pollen mother cells. Just what this change may be we are unable to say, and shall probably know no more about it until

the cytologist shall have given us some clew to the manner in which the separate qualities are represented in the chromosomes, in which the mutative changes must ensue. It is self-evident that in a mutation some characters or qualities being borne along steadily from cell to cell in the divisions must be thrown into a latent condition, or perhaps totally lost, while simultaneously or separately other qualities may be acquired, by what actual operation we do not know. It seems fairly obvious, however, that these saltations arising from the nonuniform action of the chromosomes must take place in response to some stimulus outside of the protoplast in which it actually occurs. This by no means supposes that the stimulation comes from climatic or other environmental factors, but in all probability results from enzymatic or other action from neighboring masses of cells. If this is so, then we may hope to be able to duplicate the process in our cultures and call out a proportion of mutants at our will. The results of experiments now in progress seem to lend great favor to this assumption.

This view of the case is also favored by the facts offered by bud sports, which have been designated as "vegetative" mutants, although as shown above, all mutations are essentially of a vegetative character. In the simplest forms of these sports lateral buds arising generally near the base of a shoot develop branches which diverge definitely from the characters of the main shoot, and which usually coincide with some known form, although this is not always the case. Sometimes entirely new forms arise in this manner, as in the case of seed mutants. During the present season I have been so fortunate as to have three notable examples of bud sports in the experimental cultures. One of these was a basal branch of *Oenothera ammophila* which sported into the characters of *O. biennis*, and suggesting a possible hybrid ancestry with the latter species as one of the parents. A second case was one in which a seed mutant of *O. biennis* gave a bud sport which bore the characters of the ancestral type or the true *O. biennis*. A third case was one in which a plant of one of the numerous types embraced in a complex hybrid progeny bore a branch which sported in a branch which resembled a sister type. Other anatomical relations are found. Thus a bud sport may embrace not only a branch, but a portion of the main stem, from which it arises, or in other cases it may include a section or longitudinal strip along one side of a branch, even dividing a flower or fruit, while in other cases it may be represented by single flowers or fruits scattered indiscriminately through an inflorence.

It is to be noted that in most if not all of the sectorial variations by which a part of a bud bears the divergent characters the change is a reversionary one, and the qualities that appear are really latent in the entire plant, and only need some stimulus to awaken them or some agency to weaken the dominancy of the prevalent characters.



LAMARCK'S EVENING PRIMROSE AND TEN OF ITS MUTANTS.

The dense rosette in the lower left-hand corner is *O. lamarckiana*, the parental form. *O. gigas* is in the upper right-hand corner, and under it is *O. scintillans*. The irregular rosette above *O. lamarckiana* is *O. albida*, and to the right of *albida* is *lata*. *O. oblonga* is in the upper left-hand corner.

In the case of the appearance of characters not hitherto borne by the main stock the case is not so clear, especially as we feel fairly certain that the saltations do ensue, in seed mutants at least, in single cells. Here the theoretical side of the case seemed least supported by facts, and I set about supplying the deficiency, with what success you may presently judge.

Omitting the detail of technique, I may say that strong osmotic reagents and weak solutions of stimulating mineral salts were injected into ovaries in such manner that unfertilized ovules were subjected to the action of the fluids, which killed many of them, but which gave the much-desired results in a few. In *Lamarckiana* the frequency and character of the known mutants was unaffected, but in the progeny of *biennis* was found a single individual constituting a type hitherto unknown. This single aberrant individual might have been a mutant of low frequency, comparable to *gigas* derived from *Lamarckiana*, and its recurrence here might have been merely a matter of chance. However, in another species of evening primrose, *Raimannia odorata*, a flower which belongs to a separate genus of the family and is not known to be mutating, the treatment described resulted in a large number of aberrant individuals of a hitherto unknown type. Some of these, which show a shorter life cycle than the parental form and many anatomical divergencies, have been brought to bloom and to maturity, and the new form is obviously a potential species. In this experience, exemplified by specimens of the normal parental forms and aberrant mutants, I am able to offer you conclusive proof that agencies external to the cell may induce mutations, and consequently exert a profound influence on heredity. It would not be well to exaggerate the importance of this result, yet it is evident that the establishment of this fact marks a long step forward in the experimental study of inheritance and the origin of species.

While the method described is of interest as having possibilities for our intervention in the evolution of organisms, it becomes much more so if similar results may be expected in a state of nature.

Such a parallelism is to be found in the unusual intensities of the environic factors of light, temperature, moisture, etc., which have been used by Tower in the modifications of *Leptinotarsæ* which he has secured. Here, of course, the entire soma as well as the germ plasm is subject to the action of the inciting agent. The various distributional agencies by which seeds are constantly being carried far beyond the limits of the customary range of their various environmental conditions must result in the exposure of developing individuals and mature germ plasm to unusual intensities, which might well be responsible for such results. Thus a stream takes its rise near the montane plantation of the Desert Laboratory and flows

out on the desert a few miles away and a mile lower down. Doubtless hundreds of thousands of seeds are carried to the lowlands each year. Some of these develop into individuals which carry out reproduction. This is usually done in the native habitat, at actual temperatures of the tissues not above 60° or 70° F. Down below spore formation, reduction divisions, and fertilization may ensue in temperatures 40° or 50° higher, a difference capable of being endured by the shoots of some plants now being tested, and which might well cause irreversible developmental changes. Other factors of the environment may operate in a similar manner.

Again it is to be recalled that the actual formation or intrusion of active substances in the ovarial tissues may result from the stings of insects, the mycelia of parasitic fungi, the penetration by foreign pollen, or the egg or pollen may become subject to radium emanations or to X rays or other forms of radiant energy. Still another possible action is to be accounted for: in hybridization the foreign pollen tubes, carrying the generative nuclei of the pollen parent, may encounter substances in the invaded pistil to which they are not usually subject, with the result that its capacity for transmission of parental characters may be altered, and qualities may thus appear in the progeny which are not active in either parent.

A hypothetical consideration of the known facts, as presented by the many species in which mutation has been seen to occur seems to lead to the conclusion that the changes upon which discontinuity of inheritance rests ensue previous to the reduction divisions in plants. The alterations which take place in my experiments, however, follow disturbances not brought to bear upon the germ plasm until after the second or third divisions following the reducing divisions, and are perhaps separated from this act by a considerable period of time.

The induction of such new forms in plants may be accomplished by reagents applied to the generative nuclei carried by the pollen tube, and probably by action on the embryo sac, in the period following reduction division. Mutations have been taken, on hypothetical grounds, to be based on changes occurring previous to these divisions.

A brief summary of the foregoing discussion may be made in the following generalizations:

1. Species may arise by hybridizations which result in fixed forms. A large number of forms known as species, and recognized to be of such origin, are known, and a number of them have been duplicated in experimental cultures, some of which were made over a half century ago.

2. The mutation theory groups an enormous number of hitherto unexplainable facts, to which we are constantly adding in great

volume, into a connected and meaningful whole, and, best of all, it brings the subject anew into a condition where it is amenable to experimental methods, in the laboratory and experimental garden.

3. As a result of the theoretical conceptions offered us we have been able to make repeated observations of the general principles which govern breaks, or saltations in heredity, and to observe in what manner such mutations are connected with the origin of species.

4. Having ascertained at what time in the life period of the individual mutations occur, I have been so fortunate as to secure results demonstrating that mutations may be induced in a species not hitherto active in this respect and that it is possible to call out new species by the intervention of external agents during the critical period.

5. Not less important than the foregoing is the unavoidable implication that breaks, saltations, or discontinuous action may be caused in inheritance by forces external to the protoplasts and cells which are the true bearers of the hereditary characters.

6. It is of the greatest interest to note that in the effort to correlate the larger generalizations in the various departments of science in the concept of mutation we have hit upon a principle strongly favored by a modern system of mathematics, well exemplified by the spontaneous breaking up and rearrangement of the complex atoms in radium, uranium, and allied metals, and which has been recognized by Prof. George Darwin, the physicist, in the following words:

> These considerations lead me to express a doubt whether biologists have been correct in looking for continuous transformation of species. Judging by analogy we should rather expect to find slight continuous changes occurring during a long period of time, followed by a somewhat sudden transformation into a new species, or by rapid extinction.

In the long-continued narrowing of the range of fluctuation in the various organs, coming to saltations, or direct origination of new forms, as the plant passes from generation to generation, we have as perfect a fulfillment of this motion as might be expected when an attempt is made to interpret the action of the living by the properties of the nonliving.

The most alluring feature of the whole matter, however, lies in the possibility that when the nature of the induced changes is once ascertained the inductive agents might be applied in such manner as to guide the course of development, and thus actually control the evolution of organisms. By such methods man, the conscious organism, might assume a dominating rôle in the world of organisms and create relations among living things not now existent.

LA SILLA MOUNTAIN FROM THE LOMO DEL OBISPADO, MONTEREY, NUEVO LEON.

CACTACEÆ OF NORTHEASTERN AND CENTRAL MEXICO, TOGETHER WITH A SYNOPSIS OF THE PRINCIPAL MEXICAN GENERA.

[With 15 plates.]

By William Edwin Safford.

Scarcely any group of plants in the whole vegetable kingdom is more remarkable for its strange and varied forms, the beauty of its flowers, and its wonderful adaptation to desert life, than the cactus family. To many persons the word "cactus" suggests perhaps the beautiful night-blooming cereus of our conservatories or the rosy-flowered Epiphyllums and Phyllocacti. These plants, together with the drooping epiphytal Rhipsalis, call up visions of tropical luxuriance far different from those suggested by the stiff columnar torch thistles and thorny viznagas of the arid deserts and rocky slopes of mountains. Many of the latter are figured in various government reports of explorations, in which some of the most remarkable are described at length, not only as striking features of the landscape, but also as welcome sources of refreshment to the weary traveler, and food and drink for his exhausted beasts of burden.[a]

Humboldt has somewhere spoken of the influence of collections of exotic plants upon minds susceptible to natural beauty, relating how he himself was seized with a desire to travel in tropical countries on seeing certain exotic trees in the botanical garden of Berlin. Among special collections of plants usually seen in conservatories few inspire greater interest than those composed of Cactaceæ. In this country the most important collection is undoubtedly that of the Missouri Botanical Garden, at St. Louis. Other interesting collections are those of the Department of Agriculture, at Washington, and the New York Botanical Garden, at Bronx Park. In these the plants are grouped for convenience of study according to genera, subgenera, and species, under the protection of glass roofs. Other collections, arranged more artistically and under more natural conditions, in the

[a] See Coville, Frederick V., "Desert plants as a source of drinking water." Smithsonian Report for 1903, pp. 499–505. 1904.

open air, are those of the University of Arizona, at Tucson, begun by Prof. J. M. Toumey, now of the Yale School of Forestry; and at Riverside, California, under the direction of Mr. A. S. White, who has devoted much time and money to the establishment of a magnificent cactus garden. Smaller collections are those of Prof. E. O. Wooton, at Mesilla Park, New Mexico, and a garden established at Laredo, Texas, by Mrs. Anna B. Nickels, the veteran collector of desert plants.

Mrs. Nickels has contributed much to our knowledge of Cactaceæ and other xerophytes of Texas and northern Mexico. Specimens collected by her are cited in all modern works on Cactaceæ, and many of her notes on their properties, uses, and life history are quoted. On a recent trip to Mexico the writer looked forward to visiting her in Laredo, but found that she was no longer there. Fortunately, he afterwards met her at the home of her son in the city of San Luis Potosi. Though she had left her garden behind her, she was still faithful to the objects of her early love, some of which she had carried with her on her exodus to the patio of her son's house, and there, like Göthe's Waldblümchen, "they blossom on." Nearly every plant growing in her garden she had collected with her own hands. Many of them were from the valley of the Rio Grande, but for some she had made extensive trips into Mexico, often finding it necessary to make long and painful journeys on muleback, and climbing among sharp rocks and along the escarpment of steep mountains where no animal could find foothold. From an economic view the most interesting cactus of her collection was the narcotic mescal button (*Lophophora williamsii*), which she was among the first to bring to the notice of medical men. Her observations as to its use as an intoxicant and febrifuge by the Indians were published by Prof. John M. Coulter in his "Preliminary revision of the North American species of Cactus, Anhalonium, and Lophophora."[a] For many years Mrs. Nickels sent valuable consignments of medicinal and other plants of the Mexican boundary region to chemists, manufacturers of drugs, florists, and botanists, both in the United States and Europe.

Another veteran collector to whom the National Herbarium and the Department of Agriculture are greatly indebted for Mexican plants, both living and dried, and for valuable notes on their medicinal properties and economic uses, is Dr. Edward Palmer, who at the advanced age of 78 years is still continuing the work he began in his youth. In the cactus houses of the New York Botanical Garden and the Department of Agriculture at Washington there are many living plants of his collection, the life histories of which are the subject of study by Doctors Britton and Rose; and in the pharmaceutical

[a] Contributions to the United States National Herbarium Vol. 3, p. 133. 1894.

collection of the Department are many dried specimens collected by him, of which the medicinal and chemical properties are to be studied by drug experts.

At Monterey, the capital of Nuevo Leon, the writer visited the Lomo del Obispado, on the western edge of the city, crowned by the historic Bishop's Palace, which was used as a fortification during the war between Mexico and the United States. From this hill there is a fine view of the lovely valley in which Monterey lies, with the picturesque Silla, or Saddle Mountain, beyond (pl. 1). Here I collected a number of interesting species, including the cylindrical *Mamillaria leona* (pl. 2, fig. 3), and the conical *M. conoidea* (pl. 14, fig. 1). Other species were the melon-shaped *Echinocactus horizonthalonius* (pl. 2, fig. 5), and the flatter, sharp-ribbed *Echinocactus texensis* (pl. 2, fig. 1). Many of the Echinocacti bear a general resemblance to plants of the genus Cactus, usually called Melocactus, but lack the cap of felt and bristles by which the latter are crowned (pl. 2, fig. 2). Other interesting plants were the comb-spined *Echinocereus pectinatus* (pl. 2, fig. 6), and *Mamillaria heyderi*, a little hemispherical plant with radiating bristle-like spines. There were also a few specimens of a bushy, slender-stemmed, red-fruited Opuntia I had noticed near the railway track in coming from Laredo, chiefly interesting on account of the diaphanous sheaths covering the slender needle-like spines (fig. 12, p. 547).

At the Colegio Civil, where I found a pretty collection of living cacti, I had the pleasure of meeting Prof. Emilio Rodriguez, of the Normal School of Monterey. This gentleman gave me much useful information regarding the principal localities for cactus collecting in the State of Nuevo Leon. Chief among them are Santa Catalina, near the base of the Cerro de la Mitra, a short distance west of the city; Rinconado, a mountain pass between Monterey and Saltillo; Los Muertos, just over the Coahuila line beyond Rinconado; and Icamole, to the northwest of Monterey, near the Coahuila boundary. Professor Rodriguez accompanied me on an excursion to Icamole, where we were the guests of his compadre, Don José Maria Garza Fernandez, an enthusiastic cactus lover, who has on his estate a collection of the principal cacti growing in the State of Nuevo Leon. One of the most interesting was a beautiful and rare little Mamillaria with downy plumes instead of spines. This species, *Mamillaria plumosa*, has been confused with *Mamillaria lasiacantha*, which has hairy spines; but it is quite distinct. It occurs on the Cerro del Almendrillo, about 9 miles south of Icamole, and over the boundary line at Los Muertos, in the State of Coahuila. A photograph of its plumes, enlarged 2½ diameters, is shown on plate 3, figure 6. Another interesting species was the pezuña de venado, *Ariocarpus kotschubeyanus* (pl. 3, fig. 4), a small plant with a

rosette of triangular tubercles, each marked with a median suture in such a way as to suggest the cloven hoof of a deer. It is recorded that Baron Karwinski, its discoverer, returned to Germany with only three specimens, one of which he sold for 1,000 francs. It was named by Lemaire in honor of his patron, Prince Kotschubey; though it was afterwards described as *Anhalonium sulcatum*, an appropriate name, but according to the laws of priority not tenable.

A hook-spined plant remarkable for its yellowish-green flowers crowded about the summit proved to be *Echinocactus scheerii brevihamatus* (pl. 3, fig. 3). The outer floral leaves are quite green, the innermost between green and yellow, its anthers yellow, and its stigma bright green. The tube of the perianth is scaly. The fruit is acid, but can be eaten. Another remarkable plant was *Lophophora williamsii*, the mescal button, or peyote, to which I have already referred (pl. 3, fig. 5). Instead of spines, it bears little tufts of wool on its areoles. The tubercles, separated by shallow horizontal grooves, are usually arranged in vertical lines, like a typical Echinocactus, but sometimes they are irregular, recalling those of *Echinocactus lophothele*, which I afterwards collected on the neighboring mountains (pl. 3, fig. 1). The prettiest cactus flowers in the garden were those of species of Echinocereus, with crimson or purple perianths, yellow stamens, and green stigmas. These plants are called "alicoches" in northern Mexico, and their spiny edible fruits "pitayas." The two most common about Icamole were *Echinocereus conglomeratus*, with long white pellucid needles, and a species resembling *E. stramineus*, with coarser straw-like spines. These two species are erect and grow in groups. There are one or two other species of which the stems are more slender and prostrate or procumbent. One of them, *Echinocereus berlandieri*, is shown on plate 3, figure 2. Another plant of very different habit, formerly classed with the genus Echinocereus, was *Wilcoxia poselgeri* (*Echinocereus tuberosus*), with weak, slender stems no thicker than a lead pencil, tuberous roots, and pretty rose-colored flowers with rose-colored filaments, sulphur-yellow anthers, and emerald-green 8-rayed stigma. In northeastern Mexico this plant is called "sacasil," a name which is elsewhere applied to a species of Boussingaultia, a climbing plant with tuberous roots belonging to the Basellaceæ. There were no columnar cardones, or organos, in the garden, though I was told that the common organo of the hedges of central Mexico (*Cereus marginatus*) grows at Pezqueria Chica, in the State of Nuevo Leon. *Echinocactus bicolor*, with tubercled ribs and straight spines, is not uncommon in the vicinity of Icamole, but here the spines are not bright colored like those I afterwards found at Parras (pl. 13, fig. 2). *Echinocactus capricornus* (pl. 5, fig. 2) and *Echinocactus cornigerus* (pl. 13, fig. 6), two other species growing in the garden, are also

FIG. 1.—Echinocactus texensis.

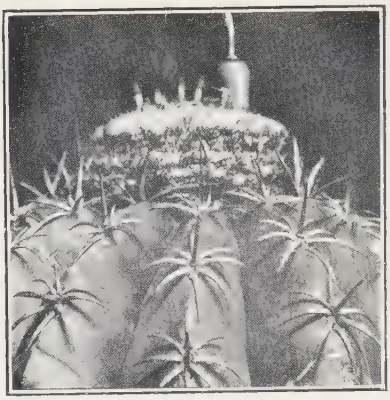


FIG. 2.—Cactus (Melocactus) maxonii.

FIG. 3.—Mamillaria leona.

FIG. 4.—Mamillaria pusilla.

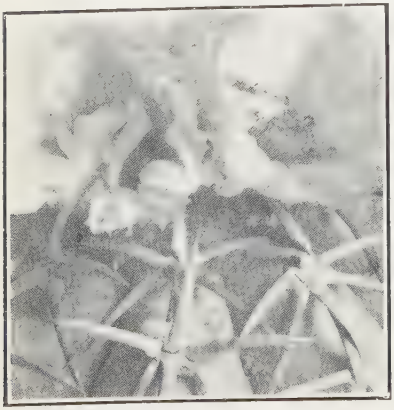


FIG. 5.—Echinocactus horizonthalonius.

FIG. 6.—Echinocereus pectinatus.

TYPES OF CACTACEÆ.

indigenous to this locality as well as *Echinocactus longihamatus*, which bears the acid limas de viznaga, used in cooking as a substitute for lemons (pl. 9, fig. 4). *Echinocactus beguinii*, covered with spines so thickly as to resemble a gray sea urchin, had been brought from the Villa de Mina, 25 miles distant from Icamole, and *Echinocactus macdowelli*, resembling a white sea urchin, from the Cañon de Santa Catalina, a short distance southwest of Monterey. *Echinocactus texensis*, locally known as "mancacaballo," or "horse-crippler," has beautifully fringed, feathery, rose-colored petals, while those of the somewhat similar *E. horizonthalonius* are nearly entire, and the bright-red fruit of *E. texensis* usually bears tufts of wool (pl. 2, fig. 1), while that of *E. horizonthalonius* is quite surrounded by wool. Several specimens of *Mamillaria leona* (pl. 2, fig. 3) were in bloom, bearing a few brick-red flowers near the crest of the plant. This color is rare in the Cactaceæ, many of them having rose-colored or crimson flowers, like those of *M. conoidea* (pl. 14, fig. 1), or white, tinged with pink or flesh color, or some shade of yellow, as in *M. bocasana* (pl. 4, fig. 4).

Don José Maria kindly offered to take us to a locality famous for the great numbers of *Echinocactus multicostatus* growing there. He obtained animals and a guide, and we were soon on our way to a mountain range about nine miles farther to the westward. Along the road were thickets of red-fruited tasajillo (*Opuntia leptocaulis*) alternating with the creosote bush (*Covillea tridentata*), and the stouter *Opuntia imbricata* with candelabra-like whorls of tubercled branches and lemon-yellow fruit. This species is locally known as "coyonostli" ("coyote prickly pear"). Afterwards I saw it growing near Durango, where it was called "cardenche." A flat-jointed Opuntia, called "cuija," was also common as well as a low pubescent species (*O. microdasys*) without spines, but with tufts of little glochidia, or barbed bristles, which are easily detached and are apt to get into the eyes of animals, often causing serious inflammation and even blindness. For this reason the plant is called "nopalillo cegador," or "blinding little nopal" (pl. 10, fig. 4). Clumps of long-spined *Echinocereus conglomeratus* were frequent. Very different in appearance from these was the dainty little lace cactus, *Echinocereus cæspitosus* (pl. 4, fig. 6), a low, cylindrical plant covered with appressed pectinate white spines so soft that the plants could be handled with impunity. The flowers of this little plant are so large that Don Manuel Fraile, an enthusiastic cactus lover, has christened them "merry widows," a name applied to the large, spreading hats recently in vogue among the ladies of the United States. Reaching our destination, we bivouacked for the night under a cloudless sky. Our camp was at the head of the Cañon de las Barretas, so named

from a thicket of barreta bushes (*Helietta parvifolia*) growing farther down the slope. The most characteristic plants of the country through which we had come were the gobernadora, or creosote bush (*Covillea tridentata*); candelilla (*Euphorbia antisyphilitica*), with rigid vertical wax-covered leafless stems; the green thorny leafless junco (*Koeberlinia spinosa*); sotol (*Dasylirion texanum*), with remotely toothed bayonet-shaped leaves; pita samandoque (*Hesperaloe funifera*), with the margins of its linear leaves bearing loose fibrous threads; and the low, rigid, sharp-leaved agave called lechuguilla, which yields much of the commercial fiber from northern Mexico.

On the very crest of the mountain range, growing in little rock pockets, we found *Echinocactus multicostatus* (pl. 4, fig. 3), the object of our search, scores of plants, with many sharp radiating ribs which look like accordion plaiting. This plant belongs to a group in which there is considerable variation of the spines. Farther south, near Saltillo, I collected plants apparently of this species, but with stouter spines, and near Aguascalientes a form with spines so numerous and broad as almost to conceal the flower (pl. 4, fig. 5). On the mountain crest associated with this plant was a rosy-flowered composite (*Pinaropappus roseus*), a pretty little daisy-like flower (*Chaetopappa modesta*) with blue-tinted rays which were just closing in sleep, and *Menodora coulteri*, sometimes called "mountain jasmine," with yellow flowers like rockroses (Helianthemum). Characteristic shrubs were a barberry (*Berberis trifoliolata*), sometimes called "palo amarillo," from its wood, which yields a yellow dye, or agritos, from its acid berries; an Acacia (*A. berlandieri*) with white odorless flowers, called "huajillo" in northern Mexico; the chapote prieto, or black persimmon (*Brayodendron texanum*); and a little farther down *Sophora secundiflora*, a bush with clusters of blue wistaria-like flowers having the odor of ripe grapes and followed by scarlet-seeded pods called "frijolillos," or "colorines."

It was pleasant to see the affection with which our host seemed to regard each little cactus plant. One of them from which the root had been broken had been thrown aside and was lying on a bare rock. He knelt down and carefully replanted it in a crevice, putting a handful of black soil about its base, saying: "*Pobrecita, déjela que viva!*"

Farther down the mountain side I collected a tiny Mamillaria (pl. 4, fig. 2), with a delicate hooked central spine on each areole surrounded by a number of spreading radials. It was very probably *Mamillaria carretii*, a species closely allied to *M. bocasana;* but that species has more than one hooked central and spreading wool-like hairs growing from each areole (pl. 4, fig. 4). Other species collected here were three Echinocacti, already mentioned—*E. horizon-*

FIG. 1.—Echinocactus lophothele.

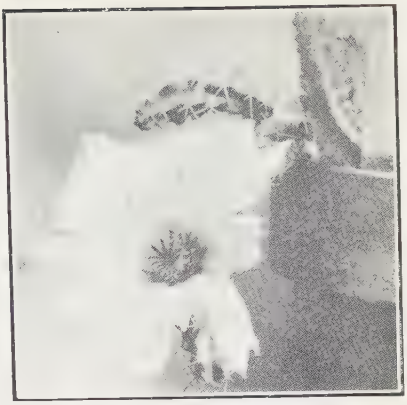


FIG. 2.—Echinocereus berlandieri.

FIG. 3.—Echinocactus brevihamatus.

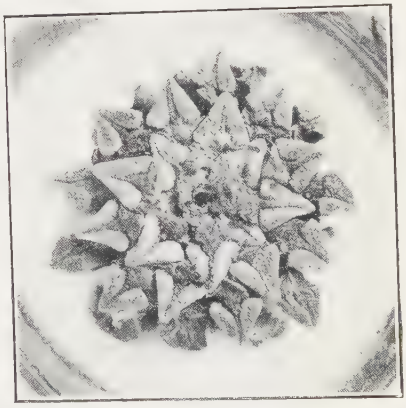


FIG. 4.—Ariocarpus kotschubeyanus.

FIG. 5.—Lophophora williamsii.

FIG. 6.—Mamillaria plumosa. × 2½.

TYPES OF CACTACEÆ GROWING IN NUEVO LEON.

FIG. 1.—Mamillaria greggii.

FIG. 2.—Mamillaria carretii.

FIG. 3.—Echinocactus multicostatus.

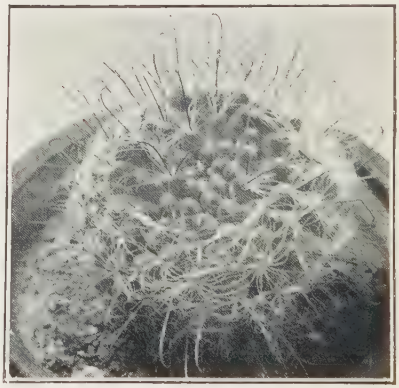


FIG. 4.—Mamillaria bocasana.

FIG. 5.—Echinocactus crispatus.

FIG. 6.—Echinocereus cæspitosus.

MEXICAN CACTACEÆ.

thalonius, *E. longihamatus*, and *E. lopothele*. Very closely allied to the last is a form collected by Mathsson, in the Rinconado Pass, between Saltillo and Monterey, named *Echinocactus rinconadensis*.

On our return trip we collected the glass-needled alicoche (*Echinocereus conglomeratus*), and the pretty little button-cactus *Mamillaria greggii* (pl. 4, fig. 1), a species very closely allied to *M. micromeris* of Texas. Like many of its congeners it bears little crimson club-shaped chilitos, which are relished for their pleasant acidulous, cranberry-like flavor. When we reached the hacienda Don José Maria insisted on adding to my collection some of the rarest species of his garden. I offered to pay for them, for I knew that he sometimes sold plants to dealers, but he declined with polite dignity to receive money, saying: "No, Señor; that would spoil all my pleasure. If I might ask a favor, however, I beg that you send me a few books which treat of Cactaceæ, books with pictures, for I can not read English nor German, and I have only this catalogue to guide me. I have some idea of the various groups of plants, but it is sometimes hard to distinguish a Mamillaria from an Echinocactus, though I know that in general the Mamillarias bear chilitos, and the Echinocacti have scaly fruits. I know of no book in Spanish to help a cactus lover, though this is the country of the Cactaceæ. Ah, Señor, what a great help illustrations are!"

I accepted Don José Maria's plants with thanks, and told him that I would try to prepare a guide to the study of Mexican Cactaceæ, such as might help an amateur collector, explaining by figures, as well as possible, the differences between the genera, describing the flowers, the structure of the plants, and the uses to which many of them are applied.

It will not be possible within the limits of the present paper to enumerate all the plants collected and observed during my recent Mexican journey. In the vicinity of Saltillo I collected many of the same species as in Nuevo Leon, including the strange-looking *Echinocactus capricornus*, with tufts of twisted spines and beautiful flowers (pl. 5, fig. 2), *Lophophora williamsii*, *Mamillaria leona*, *M. conoidea*, *Echinocereus conglomeratus*, and the species resembling *E. stramineus*. In addition to these was a species of Ariocarpus (*A. furfuraceus*), locally known as "chautle," which is quite distinct from *A. retusus* (also known as *A. prismaticus*), a species I saw in the Monterey collection, though the two species are held by some authorities to be identical.[a]

In the vicinity of Parras, Coahuila, in addition to many of the same species as those I had already collected, I found a species of Ariocarpus (pl. 5, fig. 1) very closely resembling the well-known "living

[a] Schumann, Karl. Op. cit., pp. 605–606.

rock" (*Ariocarpus fissuratus*), growing on the hills of Perote. *Echinocactus* (*Astrophyton*) *capricornus* (pl. 5, fig. 2) was also common in this locality. A variety of *Echinocactus bicolor* (pl. 13, fig. 2) had its spines most brilliantly variegated with red and yellow; and a hooked-spined Echinocactus (*E. uncinatus*) bore a close resemblance to *E. longihamatus*, except that the flowers were purplish instead of yellowish, the spines were more dense, and several centrals were hooked instead of a single one. A distinction was here made between two species of Echinocereus, apparently *E. conglomeratus* and a species with very long bluish spines. The first was called "pitahaya de Agosto," because the fruit at this place ripens in August, and the second was called "pitahaya de San Juan," because the fruit is expected to be ripe on Saint John's Day (midsummer). A cylindrical Opuntia, called "coyonostli," was apparently *O. imbricata*, which I had already collected; but a second more slender-branched species, bearing the name of "tasajillo," was quite distinct from the Monterey tasajillo, since its fruit was orange-colored instead of red and its branches somewhat stouter. A little Echinocereus, related to *E. pectinatus*, had its spines prettily colored in such a way as to form zones of red and straw color, from which it has been named "rainbow cactus."

It gives me great pleasure to acknowledge here the courtesy extended to me by the Madero family during my stay at Parras, and the kindly assistance of Dr. Alfred Walther, at whose house I found Förster's Handbuch der Cacteenkunde, edition of 1892, illustrated by a number of excellent woodcuts. Doctor Walther had established a small collection of living cacti in the principal plaza of Parras. Among the most interesting were *Cephalocereus senilis*, called cabeza de viejo, or "old man's head," from the gray hair growing from its crest (fig. 15, p. 552); *Echinocactus* (*Astrophytum*) *myriostigma*, the birreta de obispo, or "bishop's cap," from Cerravola, a short distance west of Parras; the closely allied *E.* (*Astrophytum*) *capricornus* from a barranca just south of Parras (pl. 5, fig. 2); *Echinocactus pilosus*, sometimes 4 feet high and 2 feet in diameter, with ruby-red spines and white, radiating, twisted string-like hairs; *Echinocereus caespitosus* (rainbow variety), and *Mamillaria leona*, from Llanitos, 9 miles east of Parras; the remarkable *Mamillaria cirrhifera longispina*, covered with long, tangled spines like coarse, wiry hair, from the barranca behind the neighboring Capilla; and the well-known chilito-bearing *Mamillaria meiacantha*, with pyramidal tubercles and short spines.

But the most interesting cactus of this region from a botanical point of view is *Leuchtenbergia principis* (fig. 23, p. 559) from Pata Gallina, a short distance to the southeastward of Parras, where it grows in company with *Mamillaria scheerii* and *Opuntia cereiformis*.

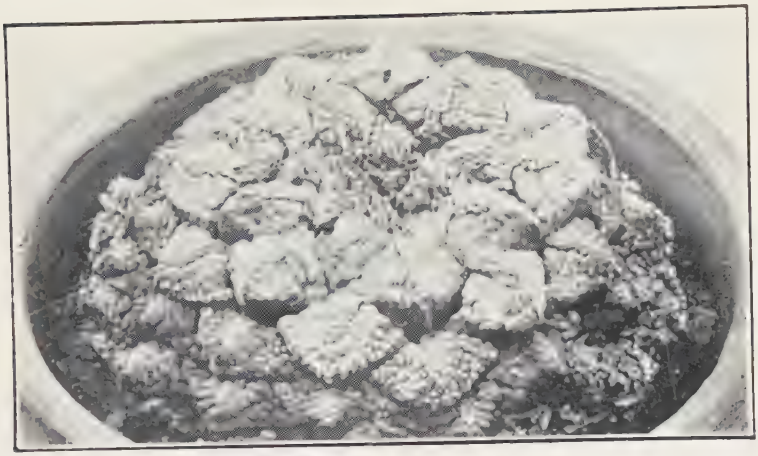


FIG. 1.—Ariocarpus fissuratus?

FIG. 2.—Echinocactus (Astrophytum) capricornus.

FIG. 1.—Hylocereus tricostatus.

FIG. 2.—Lemaireocereus queretarensis.

TYPES OF CEREUS CULTIVATED AT GUADALAJARA.

The latter species is an interesting cylindrical Opuntia belonging to the series Clavatæ, in which the spines are not sheathed in scabbards. Another species of this group is *Opuntia bulbispina*, from Perros Bravos, north of Parras, where it was collected by Doctor Gregg in 1848. Its flowers and fruit have never been described.

In addition to the cacti, there were several other xerophytes; among them an agave with remarkably short and broad leaves, called "noa," from a locality 18 miles east of Parras, on the road to Mezquite; a very narrow and rigid leaved agave, called "palmillo," from the Barranca de Llanitos, 9 miles east of Parras; and a species of Dasylirion, called "sotol," the crowns of which are used, like those of an agave, for making a fermented drink.

At Aguascalientes I collected several sheath-spined Opuntias, including the coyonostli (*Opuntia imbricata*) and the low clavellina (*Opuntia tunicata*) (pl. 10, fig. 5). Of the latter species my guide seemed to have a horror. He would repeatedly warn me: "Be careful, Señor; do not touch it; it is *muy bravo*, a plant of the devil." And, indeed, it seemed fairly to leap in eagerness to sink its barbed spines into the flesh of the unwary passer-by. The spines are easily withdrawn, but the barbed scabbards remain to fester, and can only be extracted with difficulty. On the hills above the hot springs at Aguascalientes I found only two other cacti. One, *Mamillaria uncinata*, was a low flat-topped species growing among the grass, with a single stout claw-shaped central spine, surrounded by a number of radials, and with white petals, bearing a median stripe of pink. The other was an Echinocactus to which I have already referred (*Echinocactus crispatus?*) (pl. 4, fig. 5), closely related to *E. multicostatus*, but with many broad, sword-shaped spines converging about the apex and almost concealing the flower.

At Guadalajara I had the pleasure of meeting Dr. Adrian Puga, to whom I am indebted for many courtesies. Through his kindness I obtained specimens of at least two species of Pereskiopsis, cacti related to the Opuntias, but resembling the genus Pereskia in having well developed leaves (pl. 10, fig. 2). One of these species, *Pereskiopsis aquosa*, bears edible watery fruit called "tunas de agua." Another interesting plant was a Nopalea (probably *Nopalea karwinskiana*) with beautiful rose-colored flowers, locally known as "*nopalillo de flor*." In Nopalea, an Opuntia-like genus including the plant upon which the cochineal insect is reared, the floral leaves are erect, instead of spreading as in Opuntia, and the stamens are longer than the perianth but shorter than the style (see fig. 14, p. 549). In the gardens of Guadalajara several species of climbing triangular Cerei are cultivated, all of which bear edible fruit called "pitahayas." One species has recently been described as new under the name *Cereus tricostatus* (pl. 6, fig. 1). In addition to these I noticed a columnar

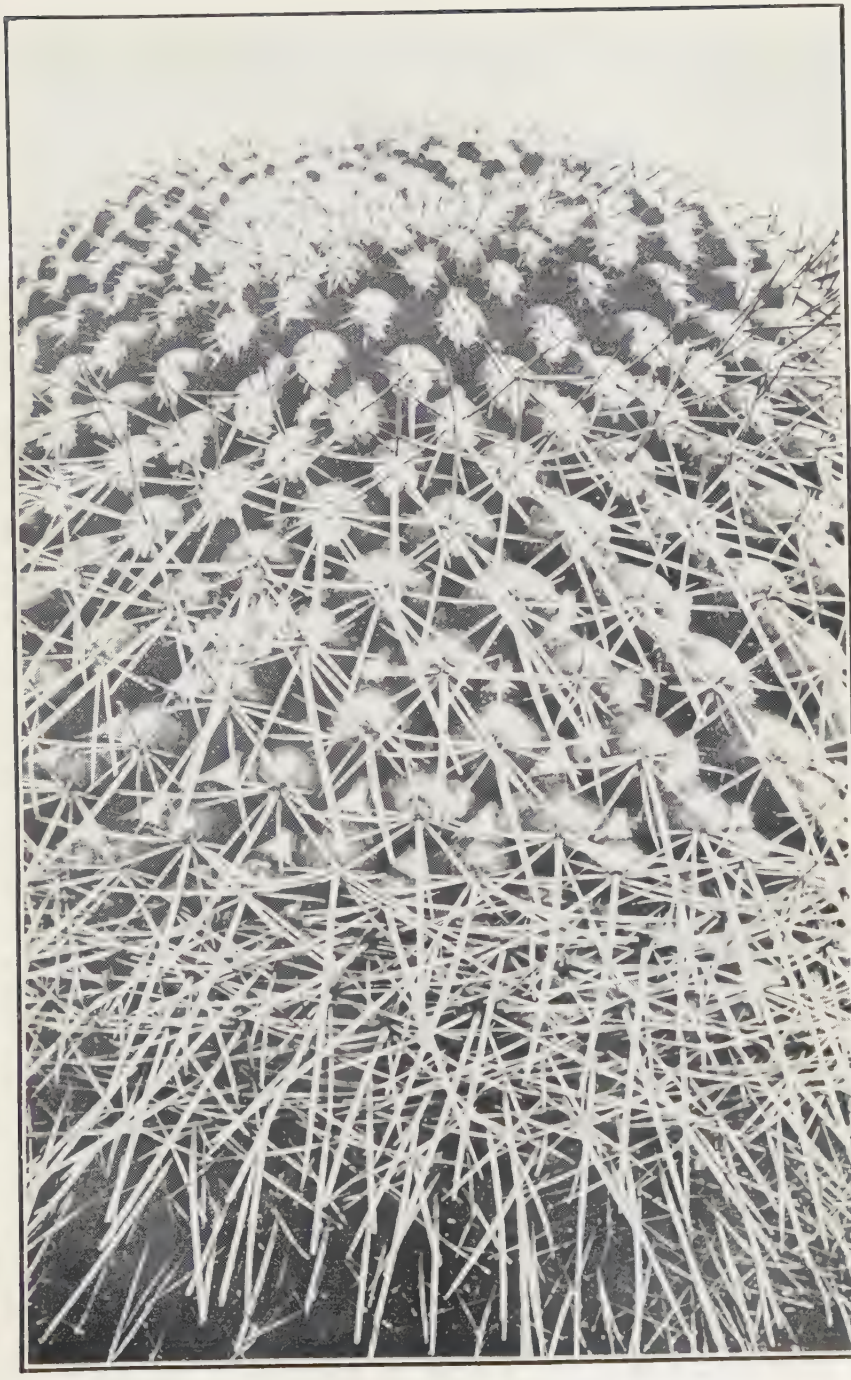
cardon, *Cereus queretarensis* (pl. 6, fig. 2), which is much planted in southern Jalisco and Querétaro.[a] At Guadalajara the natives make a distinction between the edible spiny fruit of the cardon, which they call "pitaya," and that of the climbing triangular Cerei, which they call "pitahaya." In the markets I saw a milky Mamillaria offered for sale for medicinal purposes. Milky Mamillarias are popular remedies in many parts of Mexico. In Durango the milk is used for healing cracks in the feet of the natives; elsewhere it is administered internally for various purposes.

At Guanajuato it was my privilege to meet the venerable Prof. Alfredo Dugès, so well known to the students of Mexican natural history as an accomplished botanist and zoologist. Accompanied by his collector, I climbed about the hills surrounding the city and collected several interesting cacti. In the hedges, beside the common columnar organ cactus (*Cereus marginatus*) (pl. 11, fig. 2) and the branching garambullo (*Myrtillocactus geometrizans*) (pl. 11, fig. 1), I found *Cereus queretarensis*, to which I have already referred. Here it is distinguished from the organo under the name pitahaya. Garambullo, the common name of *Myrtillocactus geometrizans*, is applied to various small currant-like fruits in Mexico.[b] The fruits of this species (pl. 9, fig. 2) are eaten either fresh or dried like raisins. On the steep dry hills of Guanajuato I collected two or three interesting milky Mamillarias, including the long-spined *M. metrizans*, is applied to various small currant-like fruits in Mexico.[b] species resembling *M. gigantea*, but not flat, as that species is described to be. In the hedges I noticed several slender-stemmed Cerei, including *Aporocactus flagelliformis*. The beautiful rose-colored flowers of this species are zygomorphous instead of perfectly regular. They are extensively used medicinally in Mexico under the name "flor del cuerno," or "horn flower" (fig. 18, p. 555).

While in the City of Mexico I was the guest of Mme. Zelia Nuttall, the archeologist, at her beautiful home, Casa Alvarado, an ancient villa situated near Coyoacan not far from the celebrated Pedregal, or lava beds. The garden of Casa Alvarado, which is several centuries old, has a number of most beautiful and interesting trees and shrubs, including a rose bush with a stem 10 inches in diameter, several conifers, and lofty palm-like yuccas. On the terrace grew beautiful cacti in pots, including cylindrical and triangular Cerei and rare Mamillarias, and over the artistic pergola spread various climbing bright-flowered Bignonias. Accompanied by one of her men I visited the Pedregal, a mass of broken angular blocks of lava, here and there perforated by great bubbles or blowholes. Every-

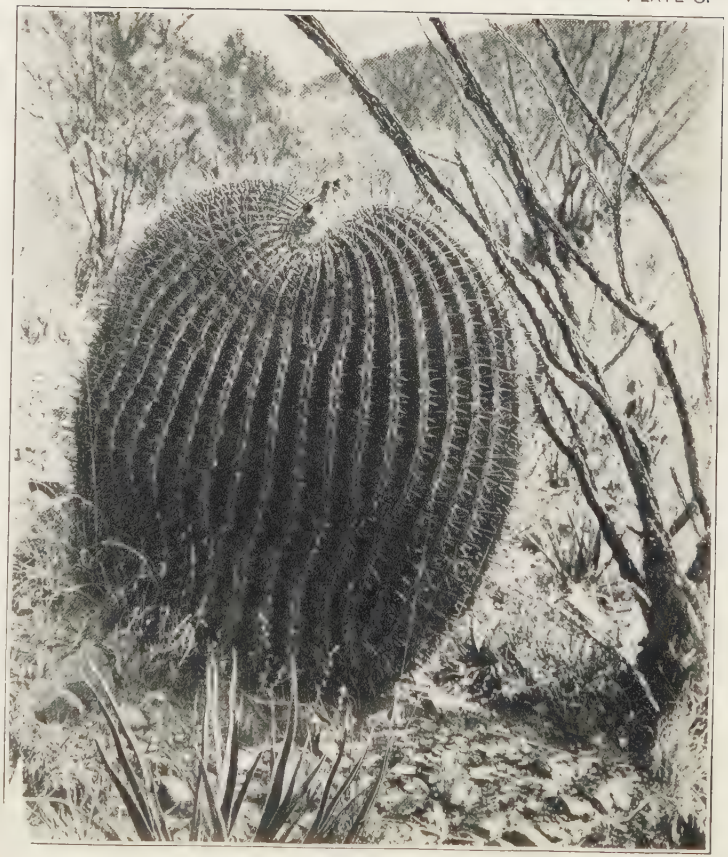
[a] See Mathsson in Monatsschrift für Kakteenkunde, Vol. 1, p. 28, 1891.

[b] In Sonora the small yellow fruit of *Momisia pallida* is called *garambullo*.



MAMILLARIA HEESIANA (NATURAL SIZE).

PLATE 8.



ECHINOCACTUS PALMERI.

thing was parched and dry at this season, and the area had been burned over, the guide said, to destroy the "infernal" *Opuntia tunicata*, the same species I had collected at Aguascalientes (pl. 10, fig. 5). Here it is called abrojos, a name applied to various spiny plants in Spain and Mexico, signifying "caltrops."

On visiting the Instituto Medico of the City of Mexico I had the pleasure of meeting Prof. Gabriel V. Alcocer, who kindly presented me with a copy of the valuable Sinonomia Vulgar y Cientifica de las Plantas Mexicanas, a work to which he contributed as collaborator of the late Dr. José Ramirez. It was a great disappointment to me to find that little effort had been made to form a collection of living Cactaceæ at the Instituto Medico. At the Museo Nacional I purchased a catalogue of the phænogamous plants in the herbarium of the museum, published in 1897 by the late Doctor Urbina. This work has been of great assistance to me, but it contains the names of only four cacti, all collected by Mr. C. G. Pringle. In the garden of the museum there was a collection of living cacti, scarcely any of which had been identified. I had the pleasure of meeting Don Manuel Urbina, the son of the celebrated botanist, who kindly presented me with a number of his father's botanical papers, including his monograph on the peyote, published in the Anales del Museo Nacional, tome 7, pages 25 to 48, 1900.

To my great regret I was obliged to start northward without visiting the wonderful cactus region of Tehuacan, in southern Puebla.

On the way from Mexico City to San Luis Potosi I passed through the country of the giant viznagas from which viznaga dulces are made. Several species are used for this purpose, the principal one being *Echinocactus ingens*. At several stations I saw specimens of these great barrel-shaped or globular plants awaiting transportation. They were in pairs, having been carried from the mountains on mule back, one strapped on each side of the animal. The rigid penetrating spines had been removed before they were started on their way to market, and consequently it was impossible to tell with certainty to what species they belonged.

At San Luis Potosi I found myself in the great tuna market. It was winter and the only tunas on sale were the deep purple, or beet-colored, tuna chaveña, usually peeled ready for eating, and the acid tuna xoconochtli, with a yellowish-pink rind, not eaten by itself but used like lemons to season dishes which would otherwise be insipid. One of the most important food staples in the market was the queso de tuna, or "tuna cheese," usually made from the celebrated tuna cardona, but sometimes also from tuna pachona, the latter being easily distinguished by its deep red color, while the former is of a

brownish yellow, with the taste of molasses candy, and of a soft pasty consistency. But the subject of the tuna as a food staple has been so ably discussed by others, that I will not here repeat what has been already said.[a]

Near the city of San Luis Potosi is situated the Cerro de Peotillos, one of the localities celebrated for centuries as a collecting ground for the narcotic peyote, or mescal button (*Lophophora williamsii*), to which I have already referred (pl. 3, fig. 5). To this hill and to Real de Catorce, farther north, the Huichol Indians of the mountains of northern Jalisco used to resort annually to obtain their supply of peyote, which was regarded by them with superstitious veneration.[b] The natives of San Luis Potosi do not use it as a narcotic, but value it as a remedy for fevers. Another curious little cactus (*Pelecyphora aselliformis*) (pl. 14, fig. 6), called "peyotillo," or "peotillo," has similar virtues attributed to it, and is sold in the drug markets of the city. Many species of cactus have been collected in the vicinity of San Luis Potosi, by Palmer, Pringle, Purpus, and other collectors; but it will be impossible to enumerate them in this paper. One of the most interesting is a large viznaga, *Echinocactus palmeri* Rose (pl. 13, fig. 1), specimens of which I saw growing on the hills about the presa, or reservoir, from which the city receives its water supply. This plant, commonly known as *Echinocactus saltillensis*, was rechristened by Doctor Rose, whose figures I here reproduce (pl. 8), because the specific name *saltillensis* had previously been applied to another species of the genus.[c] Closely allied to this are the giant viznaga of southeastern Puebla, *Echinocactus grandis*, common between Tehuacan and Esperanza; *E. ingens* of Queretaro; *E. visnaga* of San Luis Potosi; and *E. wislizeni* of Arizona, from which dulces are made.

While at San Luis Potosì I had the pleasure of meeting Don Javier Espinosa y Cuevas, owner of the celebrated Hacienda de Angostura, at which, in 1878, Doctors Parry and Palmer were guests while making their collection of Mexican plants, and where later Mr. C. G. Pringle was entertained.[d] I met also Don Octaviano Cabrera, president of the Centro Agricola de San Luis Potosì, and the distinguished Don Luis Cuevas, to whom I am indebted for many favors. It gives me pleasure to mention the courtesy of a young

[a] See Palmer, Edward. Opuntia Fruit as an article of Food. West American Scientist, Vol. 6, p. 67. 1889.

Griffiths, David, and Hare, R. F. The Tuna as Food for Man. Bur. of Plant Industry Bul. No. 116. 1907.

[b] See Diguet, Leon. La Sierra de Nayarit et ses Indigènes, p. 55. 1899.

[c] Contr. Nat. Herb., Vol. 12, p. 290, pl. 23. 1909.

[d] Pringle, C. G. Notes of Mexican Travel. Garden and Forest, Vol. 6, p. 182. 1893.

Mexican gentleman, Don José Artolózaga, who invited me to accompany him on an expedition to the magnificent presa of San Luis Potosí, of which I have spoken above.

I shall now attempt to give a short account of the Cactaceæ in general, their geographical distribution, wonderful adaptation to various conditions of soil and climate, their vegetative and floral characteristics, and the economic uses to which many of the species are applied.

Geographical Distribution of Cactaceæ.

The Cactaceæ are almost entirely confined to America, the only exception being the genus Rhipsalis, the plants of which are epiphytes, with pellucid, glutinous berries, many of them resembling rather mistletoes than cacti. It is quite possible that they may have been disseminated, like mistletoe, through the agency of birds.

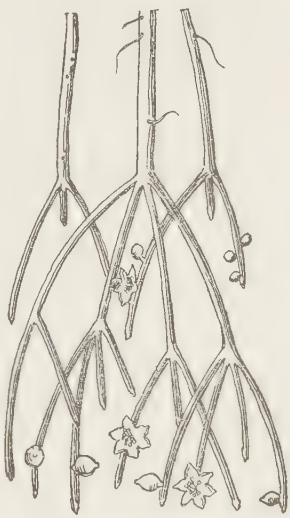


Fig. 1.—Mistletoe cactus (*Rhipsalis cassytha*).

Several prickly pears introduced at an early date into Europe and Africa have established themselves on both sides of the Mediterranean, and more recently in south Africa; and in certain regions of Australia introduced species are crowding out the indigenous vegetation to such an extent that they have come to be regarded as pests. It is quite common to regard all cacti as tropical or semitropical, but there are a number of species which withstand the frosts of winter. At least two Opuntias extend northward into British Columbia,[a] and species of Echinocereus, Echinocactus, and Mamillaria are included in the flora of Colorado.[b]

For a comprehensive account of the vegetation of the deserts of our southwestern States and of Mexico the reader is referred to Professor Frederick V. Coville's Botany of the Death Valley Expedition, published as volume 4 of the Contributions from the United States National Herbarium, 1893; and to Dr. D. T. MacDougal's "Botanical Features of North American Deserts," Publication No. 99 of the Carnegie Institution of Washington, 1908.

To the southward the family extends to Chile and Argentina. Giant torch thistles and Echinocacti are scattered over the pampas

[a] See Piper, C. V. Flora of the State of Washington, p. 396. 1906.

[b] See Rydberg, P. A. Flora of Colorado, p. 237. 1906.

of Uruguay, and melon-shaped Echinopses amid the snow and hail of the lofty Bolivian plateau. It is interesting to note that the genus Mamillaria, so well represented in Mexico, is practically absent from Costa Rica and the countries adjacent to it, the genera representing the family in that region being Cereus, Pereskia, Pereskiopsis, Nopalea, and Opuntia. These genera also occur in the warm Huasteca region of northern Veracruz and southern Tamaulipas, which is connected with San Luis Potosi by the Mexican Central Railway. Melocactus (or Cactus, as the genus is now called by Dr. J. N. Rose) is essentially West Indian and Central American; and the genus Rhipsalis referred to above, also occurring in tropical America and the West Indies, extends to Africa, the island of Mauritius, and even to Ceylon.

FIG. 2.—Skeleton of an Opuntia.

STRUCTURE.

The Cactaceæ have a woody axis more or less pronounced, usually surrounded by pulpy cellular tissue (parenchyma), in which water is stored. The transpiring surface is much reduced and the stomata are usually situated in depressions or grooves in the leathery cuticle of the stem. As an additional means for checking transpiration the cell sap is nearly always mucilaginous, and in some genera there are latex ducts filled with milky or gummy fluid. Certain species of Echinocactus (pl. 8) are like great melons or barrels and are filled with pulp of the consistency of watermelon rind.[a] On the other hand, the stems of certain Pereskias, Pereskiopses, and Opuntias become quite hard and woody. The hard, woody, reticulated skeletons of several species of Opuntia are used for various purposes, such as the manufacture of napkin rings, walking sticks, table and chair legs, and even for veneering. In some parts of South America and in Lower California, where other vegetation is lacking, the stems of cardones, or columnar Cerei are used by the natives in constructing their habitations, corrals for their animals, and even in timbering mines, and of some species the stems are dried and soaked in pitch for use as illuminating torches. Many species have tuberous roots. One of these, *Opuntia megarrhiza*, collected by Doctor Palmer at Alvarez, in the State of San Luis Potosi, is sold

[a] For an account of the transpiration, root systems, and structure of *Carnegiea gigantea*, *Echinocactus wislizeni*, and *Opuntia versicolor*, see Cannon, W. A., "Biological relations of certain cacti," Desert Botanical Laboratory publications No. 11, reprinted in the Amer. Naturalist, Vol. 40, January, 1906.

in the markets of Mexico under the name of "raiz de nopal," for use in setting broken bones, the drug venders declaring that it will cause the bones to knit speedily.

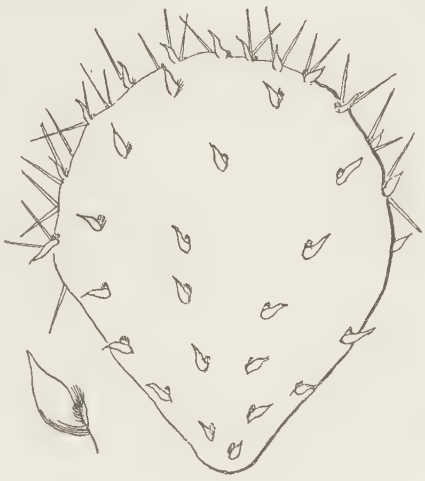


FIG. 3.—Opuntia joint, with leaves.

LEAVES AND AREOLES.

All cacti have leaves, though in some species they are rudimentary, or rather vestigial, and so small that they can not be seen with the naked eye. In others they are large and perfectly developed, either with petioles and feather veins, as in *Pereskia aculeata* (fig. 10, p. 545), sessile and fleshy, with only the mid nerve or several parallel nerves indicated, as in certain species of Pereskiopsis (pl. 10, fig. 2), or cylindrical, or awl-shaped and caducous, as in the genera Opuntia and Nopalea. In the axils of the leaves are situated the areoles. These are little cushions clothed with down or felt-like wool from which the spines issue, and in some genera the flowers also. In Opuntia and Pereskiopsis, in addition to the spines, they usually bear a tuft of small, short, barbed bristles, called glochides or glochidia.

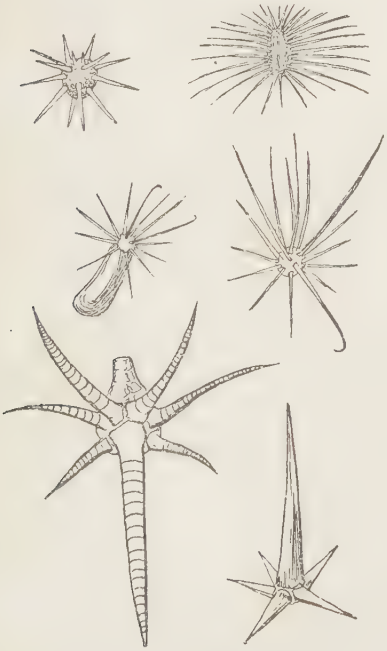


FIG. 4.—Cactus spines.

SPINES.

The spines are not connected with the woody axis of the stem or branches, but emerge from the areoles, as indicated above. In some species they are simple and straight, either bristle like, awl-shaped, or short and conical. In others they are bent like fishhooks or curved and horn-like, with transverse ribs (pl. 13, fig. 6). Sometimes they are minutely pubescent or hairy and sometimes even plumose or feathery (pl. 3, fig. 6). They may be grouped in star-like clusters, with straight or curved

rays spreading from a common center (pl. 9, fig. 1), or in pectinate fascicles with the radial spines arranged in two rows on each side of a longitudinal axis (pl. 2, fig. 6). In addition to the radial spines, there are usually erect or projecting central spines, either straight and rigid or curved. One of the most striking arrangements is that of spines of *Myrtillocactus geometrizans*, in which the central spine resembles the blade of a dagger and the radials a guard for the hilt (fig. 4, p. 539).

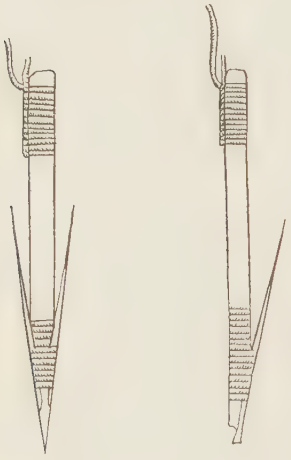


FIG. 5.—Cactus-spine fishhooks.

Cactus spines have been utilized by primitive tribes for various purposes. Dr. Edward Palmer has described the manufacture of curved fishhooks from the spines of a certain Echinocactus by the Mohave Indians of the Colorado River.[a] Fishhooks with straight shanks of bone and barbs of cactus spines were dug up by the writer from prehistoric graves at Arica, on the coast of Chile, in 1887. They were associated with other articles made of cactus spines, such as needles and combs. In December, 1891, the writer assisted at the opening of several other graves at Iquique, on the same coast, in which not only hooks and needles of the same description were found, but interesting examples of the application of cactus spines to the mending of slits in sealskins which had been used for covering the graves. In these the spines were stuck like awls through both margins and allowed to remain with the ends projecting. Around the ends thread had been passed in a zigzag manner and drawn tight, thus closing the slits tightly and effectively.

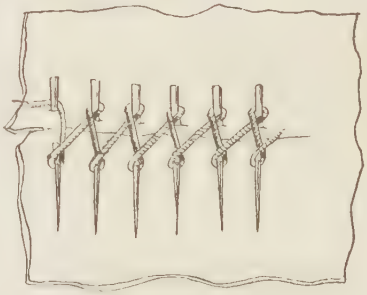


FIG. 6.—Leather repaired with cactus spines.

FLOWERS.

In most genera the flowers issue from the upper part of the areoles, but in some species of Mamillaria and allied genera they grow from between the mammillæ, or from near their base at the end of a groove extending backward from the areole. Usually they are solitary and sessile, but in the genus Pereskia they are peduncled and clustered. In nearly all genera they are conspicu-

[a] See American Naturalist, Vol. 12, p. 403. 1878.

ously colored in tints of rose, crimson, purple, yellow, orange, or copper color, and sometimes scarlet. Often they are pure white, gradually becoming suffused with rose color in age. In a few species they are comparatively sober tinted, and sometimes almost concealed beneath the spines of the plant, and in some cases they are small and inconspicuous, as in the epiphytal Rhipsalis. Some are diurnal, others nocturnal; some open at sunrise and close at night or when the sky is clouded; others open at a certain hour and close at a certain hour of the day or night; some last for several days, some for a day, and some for only a few hours.

The flowers of Cactaceæ do not possess a well-defined calyx and corolla, although the outer floral leaves are often quite sepal-like and the inner ones true petals. In one great division of the family,

FIG. 7.—Opuntia flower.

FIG. 8.—Flower of Cereus.

which has been named *Rotatiflorœ*, they are widely spreading and wheel shaped, as in the genus Opuntia; in the other division, *Tubuliflorœ*, to which Cereus belongs, the floral leaves form a tube, often remarkably long and slender, crowned with a spreading limb. The floral leaves are not arranged in definite series, but form a spiral in which the scale-like lower bracts gradually assume a sepal-like appearance and at length become broad and petaloid. In all cases the perianth crowns the ovary, and often after withering it persists as a crown to the fruit. The stamens are numerous and are inserted on the petals or perianth tube. The style is more robust and longer than the filaments. It usually expands at the summit and bears a stigma divided into several or many rays. Sometimes the stigma is brightly colored and looks like a star issuing from the dense cluster of anthers, adding no little to the beauty of the flower. This is especially the case in certain species of Echinocereus, having the bright yellow or orange-colored stamens surmounted by an emerald-green, star-like stigma and surrounded by petals of rich rose purple.

The ovary, though formed of several carpels, is always one celled. The placentæ are parietal and bear an indefinite number of anatropous ovules. In some genera (Opuntia and its allies) the funiculi, or ovule stalks, become thick and fleshy as the seeds develop, and finally form a more or less sugary pulp in which the seeds are imbedded.

FRUIT.

Pereskia has a fruit somewhat like an apple in shape with a number of leafy bracts on the skin,[a] so that in the Dutch West Indies the fruit of *P. aculeata* is called "blad-appel," or "leaf apple." In the British islands it is known as the Barbados gooseberry, and is used for making tarts and sauces, very much after the manner of true gooseberries. In some of the Pereskiopses the fruit is elongated and opuntia-like with a watery rind, as in the tunas de agua of Guadalajara, and with seeds covered with cottony hairs. In Opuntia and Nopalea the fruit is a tuna (in the ancient Nahuatl, called "nochtli"). Tunas are set with areoles like the stems or joints of the plant itself, and when immature bear leaves (pl. 10, fig. 6). These eventually fall off leaving little tufts of barbed bristles or glochidia in their axils (pl. 9, fig. 6). Many species of the genus Cereus and its allies bear edible fruit. Those of the tall columnar cardones, called pitahayas,[b] are often covered with tufts of wool and spines, which are detached easily when the fruit is ripe, leaving it covered with scars (pl. 9, fig. 5). The triangular forms of Cereus usually bear edible pitahayas also (see pl. 12), some of them of enormous size and delicious flavor, and in Texas and northern Mexico several long-spined alicoches (Echinocereus spp.) are known to Americans as "strawberry cacti," from the delightful flavor of their succulent berries (pl. 9, fig. 3). I have already referred to the acid limas de viznaga, as the fruit of *Echinocactus longihamatus* is called in Nuevo Leon (pl. 9, fig. 4), as well as to the smooth red chilitos borne by various Mamillarias (pl. 9, fig. 1) and the currant-like garambullas of the arboreous *Myrtillocactus geometrizans* (pl. 9, fig. 2). Very much like the fruit of a Mamillaria is that of the genus Melocactus, in some species of which the little chilitos issue from the crown like scarlet radishes or crimson firecrackers tipped with a fuse (pl. 1, fig. 2).

The seeds of Cactaceæ vary considerably in the different groups and are sometimes useful in making generic determinations. In Pereskia they are comparatively small with a thin black glossy testa, or

[a] See Rose, J. N. Contr. Nat. Herb., vol. 12, p. 399, pl. 54. 1909.

[b] In Central and South America the name tuna is sometimes applied to fruits of Cereus.

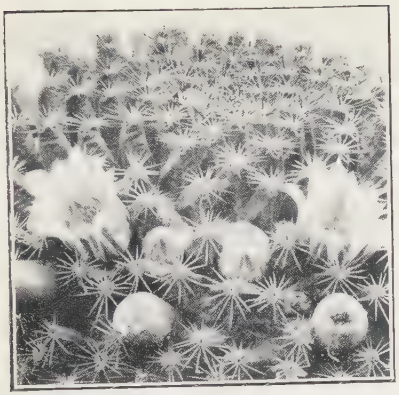


FIG. 1.—Mamillaria heyderi.

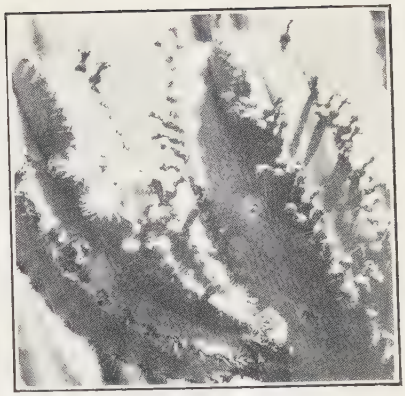


FIG. 2.—Myrtillocactus geometrizans.

FIG. 3.—Echinocereus dubius.

FIG. 4.—Echinocactus longihamatus.

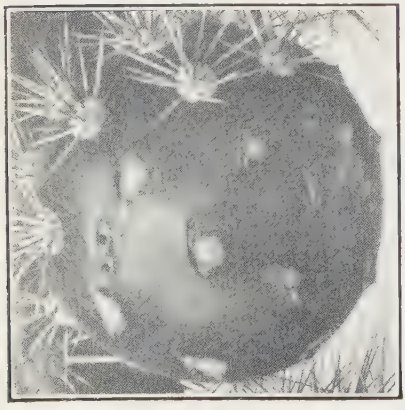


FIG. 5.—Lemaireocereus griseus.

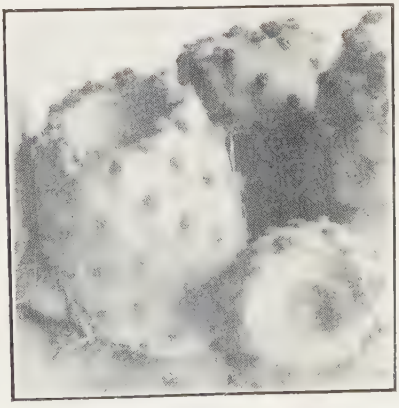


FIG. 6.—Opuntia streptacantha.

EDIBLE FRUITS OF CACTACEÆ.

shell. In Pereskiopsis they are covered with matted hairs or cotton. In Opuntia and Nopalea they are flat, hard, and bony, often margined and more or less ear-shaped in flat-jointed Opuntias (fig. 9^3), or discoid and marginless, as in many cylindrical-jointed Opuntias (fig. 9^5). In Cereus they are glossy black, either quite smooth or finely pitted (fig. 9^2), while in Echinocereus they are covered with minute tubercles (fig. 9^4). In Echinocactus they are pitted in some species and tuberculate in others. In *Rhipsalis cassytha*, they are kidney-shaped and finely granular. In one section of Mamillaria (Eumamillaria) they are glossy and marked with sunken rounded pits (fig. 9^1); in another section (Coryphantha) they are frequently smooth; while in Ariocarpus, which is quite close to Mamillaria, they are comparatively large and tuberculate. In the little *Pelecyphora aselliformis* they are kidney-shaped, while in *P. pectinata* they have a peculiar boat-like form with a very large umbilicus. The seeds of nearly all Pachycerei (cardones) are used by the Indians for food. The "higos de tetetzo" of southern Puebla (*Pachycereus columna-trajani*Q are a regular food staple and are to be found in the markets of Tehuacan in the month of May.

FIG. 9.—Cactus seeds.

CLASSIFICATION.

Beginning with Pereskia, which most nearly resembles other dicotyledonous plants, and which in all probability approaches the ancestral type of the family, Schumann divides the Cactaceæ into three subfamilies: (I) Pereskioideæ, consisting of the single genus Pereskia; (II) Opuntioideæ, composed of Opuntia and its allies; and (III) Cereoideæ, divided into two tribes, (1) *Echinocacteæ*, including *Cereus* and its allies, *Echinocactus*, *Leuchtenbergia*, *Melocactus*, *Phyllocactus Epiphyllum*, *Hariota*, and *Rhipsalis;* and (2) *Mamillarieæ*, including *Mamillaria*, *Pelecyphora*, and *Ariocarpus*.

With a few exceptions the genera and subgenera of Cactaceæ, as treated by early writers, are not sharply separated by definite limits. In many of them there are transition species which have characteristics of two genera or subgenera. Thus there are species of Echinocactus very closely resembling certain Mamillarias (Coryphanthæ) in their structure, and the relationship of several of the columnar Cerei is not clear. Various authorities have divided the old genera of Opuntia, Cereus, Echinocactus, and Mamillaria into groups, sometimes regarding them as distinct genera, sometimes as subgenera, or "series." Many of these closely allied groups differ radically from

one another, as in the structure of the seeds, yet in some cases there seem to be intermediate forms, and the flowers themselves are remarkably similar. Notwithstanding this, it would be of great assistance to the student of Cactaceæ to recognize many of the so-called subgenera as *genera*, not only for convenience of study, but also to show the systematic connection between the members of each group. In assigning the various species to a particular genus it will often be difficult to decide to which of two it belongs, but as Schumann says, this difficulty can not be avoided unless all the Cactaceæ be combined into a single genus *Cactus*.[a]

In the following synopsis of Mexican genera, while following Schumann's arrangement I shall include various genera of Opuntioideæ and Cereoideæ established by Britton and Rose, including *Pereskiopsis* and *Carnegiea*, and the classification of Cereus and its allies published by Mr. Alwin Berger in the Sixteenth Report of the Missouri Botanical Garden, 1905, and by Britton and Rose in the Contributions from the United States National Herbarium, volume 12, pages 413 to 437, 1909. I have also consulted Labouret's Monographie des Cactées (Paris, 1858); Engelmann's Cactaceæ of the Mexican Boundary, with its beautiful plates by Paulus Roetter (Washington, 1859); Lemaire's delightful little handbook, Les Cactées (Paris, 1868); Förster's Handbuch der Cacteenkunde, second edition (Leipsic, 1886); Coulter's Botany of Western Texas (Washington, 1891–1894) and his revision of the North American Cactaceæ in volume 3 of the Contributions from the United States National Herbarium (Washington, 1894–1896); Schumann's Gesammtbeschreibung der Kakteen (Neudamm, 1899); and various numbers of the Monatsschift für Kakteenkunde. The plates are reproductions of photographs by Mr. Guy N. Collins, Mr. C. B. Doyle, and Mr. E. L. Crandall, of the United States Department of Agriculture, Mr. T. W. Smillie, of the United States National Museum, and myself. The text-figures were drawn by Mr. Theodor Bolton, principally from photographs, and from the plates of Paulus Roetter already referred to.

Synopsis of Mexican Cactaceæ.

I. Subfamily Pereskioideæ.

The best known representative of this subfamily, which consists of the single genus *Pereskia*, is the Barbados gooseberry *Pereskia aculeata*, a scrambling shrub with long, slender branches armed with recurved prickles, and glossy green leaves, like those of a lemon. The flowers grow in clusters and are peduncled, unlike those of all

[a] Schumann, Karl. Keys of the Monograph of Cactaceæ, p. 6. 1903.

other genera of Cactaceæ, in which they are sessile and solitary. The petals are pale yellow or tinged with pink, the stamens yellow, and the 5-rayed stigma white. The bracted apple-shaped fruit, as I have already stated, is used in the West Indies for tarts and sauces, like gooseberries. *Pereskia tampicana*, a species closely allied to *Pereskia grandifolia* of Brazil, is a Mexican species, which has only been collected on the banks of the Rio Panuco, not far from Tampico, in the northern corner of Veracruz. Another species growing at Salinas Bay, on the west coast of Costa Rica, *Pereskia lychnidiflora*, attains the size of a small tree, and has yellowish-red flowers with petals fringed along the margin as in the genus Lychnis. Other arboreous species occur in tropical America. One of them, with long slender spines and the habit of an Osage orange, was observed by the writer in 1896 growing in hedges at Punta Arenas, Costa Rica, where it was called puipute, or matéare. It has since been described by Weber as *Pereskia nicoyana*. Associated with it was a columnar organo (*Cereus aragoni* Weber) with edible fruit locally known as tunas de organo. *Pereskia autumnalis* (plate 10, fig. 1), called manzanote in Guatemala, was collected by O. F. Cook, of the United States Department of Agriculture, in 1902, at El Rancho, near Zacapa, Guatemala. Excellent photographs of this species by Guy N. Collins have recently been published by Rose, in Contributions from the National Herbarium, volume 12, pages 399, plates 52,

FIG. 10.—Pereskia aculeata.

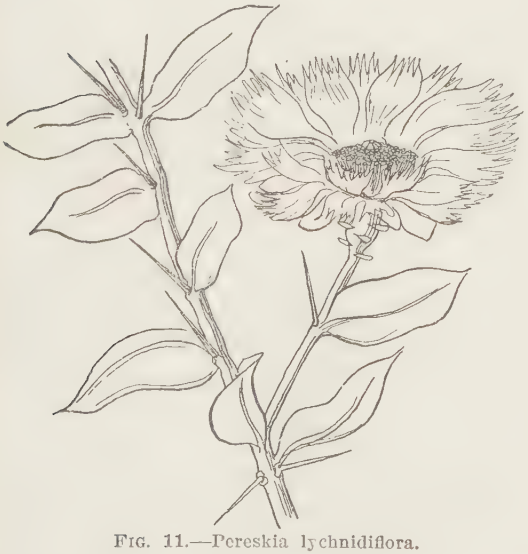


FIG. 11.—Pereskia lychnidiflora.

53, 54, 1909. According to Professor Pittier the fruit is eaten by cattle during the dry season. The lens-shaped seeds have a glossy testa, which serves to distinguish this genus from the somewhat similar Pereskiopsis, in which the seeds are covered with matted hairs.

II. SUBFAMILY OPUNTIOIDEÆ.

This subfamily is distinguished by the leaf-like cotyledons of its seeds; its fleshy leaves, either broad and lasting, as in Pereskiopsis (pl. 10, fig. 2), or small, terete, and caducous, as in Opuntia and Nopalea; and by the barbed bristles, or glochidia, borne on the areoles, usually small and very numerous and mixed with soft wool. These glochidia are extremely sharp and barbed. They are loosely attached at their insertion, so that they are loosened by the slightest touch and adhere most annoyingly to the skin or clothing. In this subfamily the spine-bearing and the flower-bearing areoles are united into one circular pulvillus in the axil of the leaf. The spines occur in the lower and the bristles in the upper part of the pulvillus. Between the glochidia and surrounded by them, and always above the spines, the young shoot or flower originates (pl. 10, fig. 6). These glochidia correspond with the bristles and wool in the axils of some Eumamillaria and with the tomentum of the floriferous areole in Coryphantha and Echinocactus; but they are quite distinct morphologically from the spines themselves. They continue to grow year after year, becoming longer and more numerous, and in many species the spines themselves continue to grow and increase in number.[a]

1. *Pereskiopsis.*—This genus, with broad, fleshy leaves, needle-like spines, glochidia, opuntia-like fruit, and seeds covered with matted hairs, is represented in Mexico by several species. In the vicinity of Guadalajara the fruit of *Pereskiopsis aquosa* (pl. 10, fig. 2) is gathered for food and sold in the markets as "tunas de agua." It has subspatulate-elliptical, sessile, acuminate leaves, which are obscurely 5-nerved. The areoles, which are scantily provided with wool, bear at length usually a single white or grayish spine tipped with brown. The edible part of the fruit is the watery endocarp, or rind, which has an agreeable odor and taste, somewhat like that of an apple. The seeds are margined distinctly, with the margin prolonged into a kind of tail-like process extending over the funiculus, or seed stalk, and are clothed with cotton-like fiber. Consequently they are quite different from the smooth, glossy, lens-shaped seeds of Pereskia, and would alone serve to distinguish Pereskiopsis from that genus. Another species from the same locality is *Pereskiopsis calandriniæfolia*, with broad, spatulate leaves and prominent cushions of felt on the areoles, from which several long, slender,

[a] Engelmann, Cactaceæ of the Mexican Boundary, p. 45. 1859.

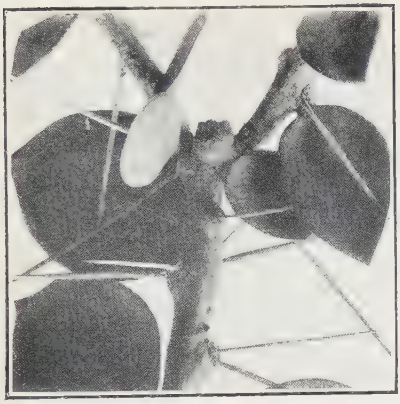


FIG. 1.—Pereskia autumnalis.

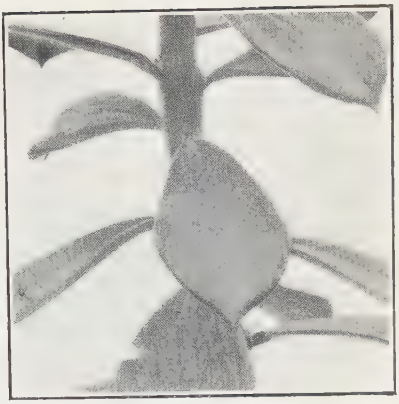


FIG. 2.—Pereskiopsis aquosa.

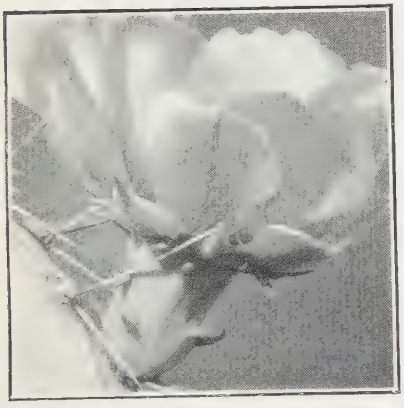


FIG. 3.—Opuntia arizonica.

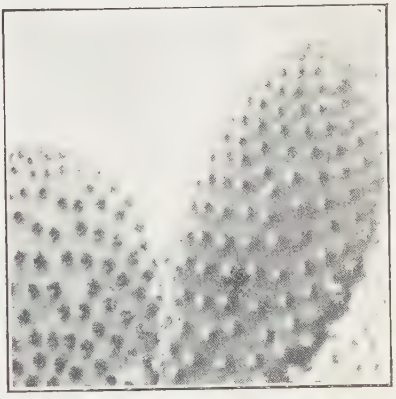


FIG. 4.—Opuntia microdasys.

FIG. 5.—Opuntia tunicata.

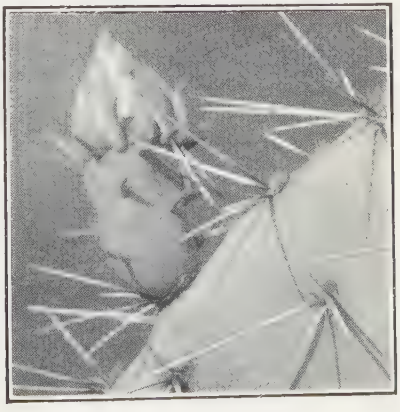


FIG. 6.—Opuntia arizonica.

LEAVES AND SPINES OF CACTACEÆ.

needle-like brown spines protrude. This species is locally known as "alfilerillo," or "tasajillo," from its resemblance when leafless to the true tasajillo (*Opuntia leptocaulis*). Other species are the slender-stemmed *Pereskiopsis spathulata*, *P. pititache* of Tehuantepec, the very similar *P. brandegeei* of Lower California, *P. chapistle* of Oaxaca, and *P. porteri*, the "yellow rose" of Sinaloa.

2. *Opuntia.*—Formerly this genus was divided into two sections; Platopuntia, including plants with flattened joints; and Cylindropuntia, with joints cylindrical or terete. Various other classfications have been proposed, the latest and most satisfactory of which is that of Britton and Rose,[a] who divide the genus into a number of groups which they call "series." Among those occurring in Mexico are the following:

Clavatæ, in which the joints are cylindrical or clubshaped and the spines unsheathed. Examples: *Opuntia bulbispina*, a prostrate species with spines bulbous at the base, often forming thickets in the State of Coahuila, north of Parras; *Opuntia emoryi* of Chihuahua and Sonora; and *Opuntia bradtiana* (*Cereus bradtianus* Coult.), a cereus-like erect species growing in Coahuila.

FIG. 12.—Tasajillo (*Opuntia leptocaulis.*)

Cylindraceæ, with comparatively stout joints, and spines sheathed in scabbards, including the coyonostlis, or cardenches, *Opuntia imbricata* and *O. arborescens*, and the clavellinas, or abrojos, *Opuntia tunicata* (pl. 10, fig. 5).

Monacanthæ, also with sheathed spines but with slender-branched stems and a bushy habit of growth; including the tasajillos of northern and central Mexico *Opuntia leptocaulis* (fig. 12), with scarlet or coral-red fruit, and *O. kleiniæ*, with somewhat stouter stems and yellowish fruit. An interesting feature of these plants is that the fruit is often proliferous; that is, branches and flowers frequently grow from the areoles of the cuticle covering the fruit itself.

Pubescentes, with pubescent joints and sometimes without spines, though usually rich in bristles; including *Opuntia rufida* and *O. microdasys* (pl. 10, fig. 4), usually called "nopalillos cegadores,"

[a] Britton and Rose. A preliminary treatment of the Opuntioideæ of North America. Smithsonian Misc. Coll., vol. 50, p. 503. 1908.

and *O. durangensis* and *O. leucotricha*, which bear the tunas duraznillos of Durango and central Mexico.

Crinifera, with long wool growing from its areoles, including the nopal crinado of the State of Puebla (*Opuntia pilifera*).

Vulgares, prostrate plants unarmed or with a few spines, including our own little prickly pear of the eastern United States (*Opuntia opuntia*).

Subinermes, upright plants scarcely armed at all or even spineless, including the nopal de tuna Castilla (*Opuntia ficus-indica*), now so widely spread about the Mediterranean and in tropical America; the various varieties known as "tunas mansas" ("tame prickly pears") in Mexico; and the tuna camuesa (*O. larreyi*), cultivated about Queretaro.

Setispinæ, low plants with small joints and fine bristle-like spines, including *Opuntia filipendula* and *O. setispina* of Texas and Chihuahua.

Tunæ, bushy plants, often with abundant yellow spines, including the common prickly pear of Texas and Tamaulipas (*O. lindheimeri*), the cuija (*O. cuija*) of northern and central Mexico, and *O. tuna* of the West Indies and gardens of Mexico, with edible red fruit and yellow or red flowers.

Fulvispinosæ, bushy or spreading plants with brown or partly brown spines and fleshy fruits, including nopal de raiz of the Alvarez Mountains (*O. megarrhiza*), *O. engelmanni* of northern Mexico and Texas, and *O. arizonica* (pl. 10, figs. 3 and 6).

Albispinosæ, robust plants with white spines and broad petals, including the tuna cardona (*Opuntia streptacantha*) of San Luis Potosi, from which such enormous quantities of "tuna cheese" are made.

Stenopetalæ, large white-spined plants with narrow petals, including *Opuntia stenopetala*, which was first collected on the battlefield of Buena Vista, south of Saltillo, Coahuila.

The flowers of Opuntia (pl. 10, fig. 3) are for the most part yellow or orange, but in some species they are rose colored or crimson. One of the loveliest is the rose-colored flower of *Opuntia basilaris* of the southwestern United States. In all cases the perianth opens widely and the stamens are not so long as the petals. These features serve to distinguish the Opuntia from the closely allied genus Nopalea. The fruit ("tuna") of many species and varieties of Opuntia (pl. 9, fig. 6) is edible and is an important food staple.[a] The young, tender mucilaginous pads are cut into strips ("nopalillos") and cooked like string beans, and the pads ("pencas") are also extensively used as

[a] See Griffiths, David, and Hare, R. F. The Tuna as food for man. U. S. Dept. Agr., Bur. Plant Industry Bul. 116. 1907.

food for cattle in arid regions. The rigid, sharp spines with which most species are armed (pl. 10, fig. 6) is a serious drawback in feeding them to cattle, but these are frequently removed by singeing the pads with a torch. Efforts have been made to propagate spineless forms, and these have in many cases been successful.[a]

3. *Nopalea.*—This genus is closely allied to Opuntia, but it may easily be distinguished by its flowers, the perianth of which is erect instead of widely spreading, and the stamens are longer than the petals, though they are exceeded by the style. The most important species of this genus is *Nopalea coccinellifera*, the "nocheznopalli" on which the cochineal insect is reared. The flower is of a beautiful rose color or crimson. The fruit is edible, but is inferior to most of the Opuinta fruits sold in the Mexican markets. The plants are usually more or less tree like, growing to a height of 3 or 4 meters, with the trunk and older branches cylindrical or nearly so. The younger parts are flat and green, the joints oblong or ovate and compressed, usually spineless when young, and bearing small, fleshy caducous leaves like those of Opuntia, but sometimes becoming spiny when older. This plant was extensively cultivated by the Mexicans before the discovery of America, for the sake of the dye-yielding insect which feeds upon it. Its cultivation was afterwards introduced into Guatemala, Honduras, the Canary Islands, Algeria, Java, and Australia. In recent years cochineal has largely been supplanted by aniline dyes, and its cultivation has been discontinued in nearly every place but the Canary Islands. The principal sources of its supply were formerly the states of Guerrero and Oaxaca. Other species of the genus growing in Mexico are *Nopalea dejecta* (called nopal chamacuero, at Victoria, Tamaulipas), which has narrowly oblong joints armed with whitish spines, and *N. karwinskiana*, which grows in the vicinity of Colima, on the Pacific coast. It is probably this species which grows about Guadalajara,

FIG. 13.—Opuntia flower, vertical section.

FIG. 14.—Nopalea flower.

[a] See Griffiths, David. The Prickly Pear as a farm crop. U. S. Dept. Agr., Bur. Plant Industry Bull. 124. 1908.

in the State of Jalisco, where it is called "nopalillo de flor." A new species (*N. guatemalensis*) with linear reflexed leaves and very spiny areoles was recently described by Doctor Rose from specimens collected in Guatemala by Mr. William R. Maxon, of the United States National Museum. According to Professor Pittier, who obtained flowers and spines of this species at Zacapa, it is locally known as tuna lengua-de-vaca, or "cow's-tongue prickly pear." Figure 14, page 449, was made from Professor Pittier's photograph.[a]

III. SUBFAMILY CEREOIDEÆ.

In this group there are no glochidia, the spines are never barbed, and the leaves are reduced to scales often so minute as to be invisible to the naked eye. The ovules are not covered by the expanded funiculi; the seeds, instead of being bony and ivory colored, as in the Opuntioideæ, have dark, thin, glossy shells, either quite smooth, or pitted, or covered with wartlike tubercles; and the cotyledons, instead of being leaflike, as in the Opuntioideæ, are more or less globose.

Schumann divides this subfamily into two tribes: (1) *Echinocacteæ*, including Cereus and its allies, Echinopsis, Echinocactus, Leuchtenbergia, and Melocactus, forming the subtribe *Armata*, which is characterized in general by stout, spiny stems; and Phyllocactus, Epiphyllum, Hariota, and Rhipsalis, forming the subtribe *Inermata*, with spineless and leaflike or slender cordlike stems; and (2) *Mamillarieæ*, including Mamillaria and its allies, Pelecyphora and Ariocarpus.

In most of the Echinocacteæ the flowers are tubular and the ovary and fruit either scaly or covered with little tufts of wool from which spines issue. In Rhipsalis, however, the flowers are wheel shaped. The fruits of some species of the Cereus group are unarmed, while in Cactus (Melocactus) the smooth, red, club-shaped fruit resembles the "chilitos" of a Mamillaria. Areoles, or pulvilli, as they are sometimes called, are composed of two parts, aculeiferous, or spine bearing, and floriferous, or flower bearing. In Echinocactus these are either united into a single areole or are separated by a short groove (as in *Echinocactus scheeri*). In *Echinocereus* the flower or young bud bursts through the epidermis above and close to the spiniferous areole. On the other hand, in some divisions of Mamillaria the spine-bearing and flower-bearing areoles are quite separate, the flowers appearing to spring from between the tubercles of the plant (pl. 9, fig. 1), while in the subgenus (or genus Coryphantha the two areoles are joined by a long groove, and the flowers, growing from the nascent or very young tubercles, appear to spring from the apex of the plant (pl. 14, fig. 3) very much as in the group of the

[a] See Rose, J. N. Nopalea guatemalensis, a new cactus from Guatemala. In Smithsonian Misc. Collections, vol. 50, p. 330. 1907.

tubercled Echinocacti to which *E. hexaedrophorus* (pl. 13, fig. 3) and *E. scheerii* (pl. 3, fig. 3) belong.[a]

Tribe Echinocacteæ.

1. *Cereus and its allies.*—The plants which have been grouped together under this name vary considerably in the characters of their flowers and fruit. They naturally form several distinct divisions which have been regarded by various authors as subgenera, or, in a few cases, as genera. Among the most recent authorities to treat of the group are Britton and Rose, who have established a number of new genera and have raised the giant sahuaro, or suguaro, of our southwestern deserts into a monotypic genus, named Carnegiea,[b] after Mr. Andrew Carnegie, to whose generosity the Desert Laboratory of the Carnegie Institution owes its existence.[c] The most important studies of the genus thus far have been those of Mr. Alwin Berger, published in the Sixteenth Report of the Missouri Botanical Garden, 1905, and Britton and Rose in volume 12 of Contributions from the National Herbarium, pages 413 to 437, 1909. From the classification of Berger and from Britton and Rose I take the following list of genera:

Cereus, as understood by Britton and Rose, includes *Cereus hexagonus* (usually called *C. peruvianus*) and *C. jamacaru*, night-flowering cacti with columnar upright, branching, ribbed, fluted, or angled stems and branches, and beautiful white flowers with numerous stamens and many-rayed stigma. Though of South American origin these species are now widely spread in the West Indies, the first also in Central America and tropical Mexico.

Rathbunia, named by Britton and Rose in honor of Dr. Richard Rathbun, Assistant Secretary of the Smithsonian Institution in charge of the U. S. National Museum, includes several species indigenous to the coast of Western Mexico, among them *Rathbunia alamosensis* (*Cereus alamosensis* Coulter), a plant with sharp irregular ribs, brown velvety areoles, stout spines, and bright salmon-colored trumpet-shaped day-blooming flowers, first collected by Doctor Palmer, near Alamos, southern Sonora.

Nyctocereus, the type of which, *Nyctocereus serpentinus*, called junco espinoso in the State of Jalisco, is often seen in collections. This species has straggling cylindrical fluted stems and branches with numerous areoles bearing a tuft of white wool and weak radiating

[a] Engelmann, George. Cactaceæ of the Mexican Boundary, p. 46. 1859.

[b] Britton, N. L., and Rose, J. N. A New Genus of Cactaceæ. Journ. New York Bot. Garden, vol. 9, p. 185. 1908.

[c] See Coville, Frederick V., and MacDougal, D. T., "Desert Botanical Laboratory of the Carnegie Institution," Publication No. 6 of the Carnegie Institution of Washington.

bristle-like spines. The large white flowers are night blooming, and the fruit contains a few large seeds imbedded in red pulp.

Cephalocereus, in which the flower-bearing portion is differentiated from the rest in the form of a woolly head, or cephalium, near the apex of the stem, either symmetrical and terminal or one-sided. The fruit (fig. 16), covered with a bare skin becomes shriveled with age. Examples: *Cephalocereus senilis*, the cabeza de viejo, or old man's head, of the limestone cliffs of Hidalgo, Guanajuato, and Puebla; *C. cometes*, of San Luis Potosi; and *C. palmeri* ("organo"), of Victoria, Tamaulipas.

FIG. 15.—Cephalocereus senilis.

Lophocereus, in which the stem and branches are ribbed very much as in Myrtillocactus, and the areoles are remote on the sterile portions but crowded on the flower-bearing branches, and on the latter produce short white wool and long stiff bristles. Example: *Lophocereus schottii*, the sina or sinita (old-man cactus) of Sonora and Lower California.

Myrtillocactus, which may be recognized by its short trunk, bluish-green branches curving upward, with six ribs, which form a starlike cross section and are armed with stout dagger-like spines, usually with a stout laterally compressed central and 5 radials about its base. Example: *Myrtillocactus geometrizans* (pl. 11, fig. 1) which yields the small fruit called "garambullas."

FIG. 16.—Cephalocereus fruit.

Pachycereus includes several giant cardones of the Pacific coast region, among them *P. pringlei* and *P. pecten-aboriginum*. The first of these may be recognized by the little spheres of yellowish tomentum with which its fruit is covered (fig. 17); the second by its spiny fruit, resembling great chestnut burs, which the Indians use for hairbrushes. The seeds of these species are parched, ground, and used for food. The common organo of central Mexico, is placed in this genus by Britton and Rose, under the name *Pachycereus marginatus* (*Cereus gemmatus* Zucc.). This species is much used for hedges (pl. 11, fig. 2). Its fruit is not edible and the areoles are so close together as to form almost a continuous line along the ribs. The spines are short and inconspicuous and often become obsolete on old plants. Another species belonging here is the tetetzo of southern Puebla (*P. columna-trajani*).

FIG. 1.—Myrtillocactus geometrizans.

FIG. 2.—Pachycereus marginatus.

ARBOREOUS CACTACEÆ OF GUANAJUATO.

Escontria includes a single species, the chiotilla, or xiotilla, of southern Puebla and Oaxaca (*Cereus chiotilla* Weber).

Carnegiea includes the giant sahuaro, or suguaro (*Cereus giganteus*), already referred to, the fruit of which, called "pitahaya," is an important food staple of the Indians, but is not so highly esteemed as the pitahaya dulce of *Lemaireocereus thurberi.*

Lemaireocereus, as proposed by Britton and Rose, includes plants of widely different habits. Under this genus are placed the pitahaya agria (*Cereus gummosus* Engelm.) and the chirinole, or chilenola, of Lower California (*Cereus eruca* Brandeg.), both of them prostrate plants with scarlet pitahayas containing pleasantly acid pulp; the columnar pitahaya dulce of Sonora and Lower California (*Cereus thurberi* Engelm.); and the pitahaya of Mexico and Central America, *Cereus griseus* Haw. (*C. eburneus* Salm-Dyck), figured by Rose in vol. 12 of the Contributions from the National Herbarium, pl. 67, from a photograph taken by G. N. Collins at El Rancho, near Zacapa, Guatemala. Another species assigned to the genus is *Cereus weberi* Coulter (*Cereus candelabrum* Weber), the massive organo so characteristic of the scenery about Tomellin, on the way from Tehuacan to Oaxaca, with its numerous thick crowded vertical branches rising from a short central trunk.

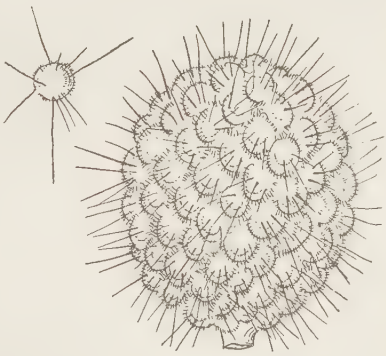


FIG. 17.—Pachycereus pringlei, fruit.

Peniocereus, with the single species *Peniocereus greggii* (*Cereus greggii* Engelm.) is remarkable for the enormous fleshy root, from which the slender 4-ribbed or 5-ribbed stem rises. The large white nocturnal flowers are remarkable for their very long slender tube, bearing small clusters of spines on its outer surface. The ovoid, long-acuminate scarlet fruit, bearing elevated spineless areoles, is edible. Excellent figures of this plant are published by Rose (l. c., p. 428, plates 74 and 75) from photographs taken by Francis E. Lloyd near Tucson. The range of the species extends to northern Mexico, Texas, and Arizona.

Hylocereus includes the well-known *Cereus triangularis* and *Cereus trigonus*, as well as *C. ocamponis* and *C. napoleonis.* There is much confusion between the first two mentioned, but *Hylocereus trigonus* (pl. 12), founded by Haworth on Plumier's plate 200, figure 2, published in 1755, may be recognized by the salient points of its angular

ribs, which bear the areoles, while in *H. triangularis* the areoles are borne in the notches of the crenations of its compressed wing-like ribs.

Selinocereus, with large white fragrant night-blooming flowers, includes the queen-of-the-night cactus (*Cereus grandiflorus*), known in Tamaulipas, Mexico, as organillo; the common "night-blooming cereus" of our conservatories, *Cereus pteranthus* (*C. nycticalus* Link), and *Cereus hamatus*, with remote hook-like processes along the ribs.

Acanthocereus, as treated by Schumann, has a single species which has received various names: *Cereus princeps* Pfeiff., *Cereus variabilis* Engelm. (not Pfeiff.), and *Cereus baxaniensis* Karw. It has now been identified as Linnaeus's *Cactus pentagonus*, and should therefore be called *Acanthocereus pentagonus* Britt. and Rose. It is a night-flowering cactus with erect or reclining 3 to 6 angled stems, the areoles distant, bearing 4 to 6 stout, radiating, unequal spines. The flowers have long tubes, green sepals and white petals; the oval spiny fruit (pitahaya) is bright scarlet with thick black seeds and luscious red pulp. This species occurs on both sides of the Rio Grande and extends southward along the Mexican coast into Central America. It also occurs in the West Indies.

Heliocereus, with crimson or purple-red flowers, includes the well-known *Cereus speciosus* of conservatories and the very closely allied *C. coccineus* and *C. schrankii*. In the state of Jalisco *H. speciosus* is sometimes called Santa Maria, or xoalácatl. It has large purple-red flowers with an iridescent bluish center, which remain open for several days. The 3 to 5 ribs are serrated, the areoles occupying the short upper side of the serrations, bear white wool and clusters of 5 to 8 stiff, slender, sharp-pointed spines, the under one yellow and bristle-like.

Wilcoxia includes two slender-stemmed species with large fleshy roots: *Cereus poselgeri* (*Cereus tuberosus* Poselg.), called sacasil in Nuevo Leon, with stems as thick as a lead pencil, purple flowers, and woolly fruit bearing black and white bristles; and *Cereus striatus*, with stems no thicker than straws, soft harmless spines, purple flowers, and scarlet spiny fruit. The latter species was collected by Dr. Edward Palmer on Carmen Island, Gulf of California. It occurs on the peninsula of Lower California and in Sonora, where its common name is sacamatraca, saramatraca, or pitayita. It is identical with the plant described by Weber as *Cereus diguetii*.

Aporocactus includes the slender stemmed rat-tail cactus, *Cereus flagelliformis* (fig. 18), with beautiful rose-colored or crimson zygomorphic flowers, which are sold in the drug markets of Mexico under the name of flor de cuerno, for use as medicine.

Echinocereus is characterized by diurnal flowers, comparatively short and rarely tubular. The ovary and tube bear prickly and woolly

areoles; the floral leaves are usually showy and more or less spreading, the stamens numerous and inserted along the tube, the style longer and ending in the several-rayed green stigma (fig. 19). Schumann recognizes several subsections; among them, Subinermes (including *E. pulchellus* and *E. subinermis*), Prostrati (including *E. scheeri*, *E. berlandieri*, *E. procumbens*, *E. cinerascens*, *E. enneacanthus*, *E. leonensis*), Erecti pectinati (including the pectinately spined *E. ctenoides*, *E. chloranthus*, *E. longisetus*, *E. pectinatus*, *E. cæspitosus*, *E. roetteri*), Erecti decalophi (including the needle-spined *E. acifer*, *E. conglomeratus*, *E. dubius*, *E. merkeri*, *E. stramineus*). Among the plants mentioned above *E. cinerascens*, with decumbent clustered stems, yields an edible spiny fruit with the flavor of a raspberry; several of the pectinate spined forms have zones of red and white or yellowish, owing to the color of the spines, and are known as "rainbow cacti;" and *E. stramineus* and its close allies are known as strawberry cacti, from the edible fruit they bear.

FIG. 18.—Aporocactus flagelliformis.

Cereus fruits.—The fruits of many species of Cereus and allied genera are juicy, fine flavored, and nutritious. Their general name throughout Mexico is pitahaya, a word of Carib, or Haytian, origin, early brought to Mexico by the Spanish conquistadores, and sometimes modified to pitaya, or to its diminutive form pitayita. The following description of a pitahaya was given as early as 1535, by Oviedo:

FIG. 19.—Echinocereus flower.

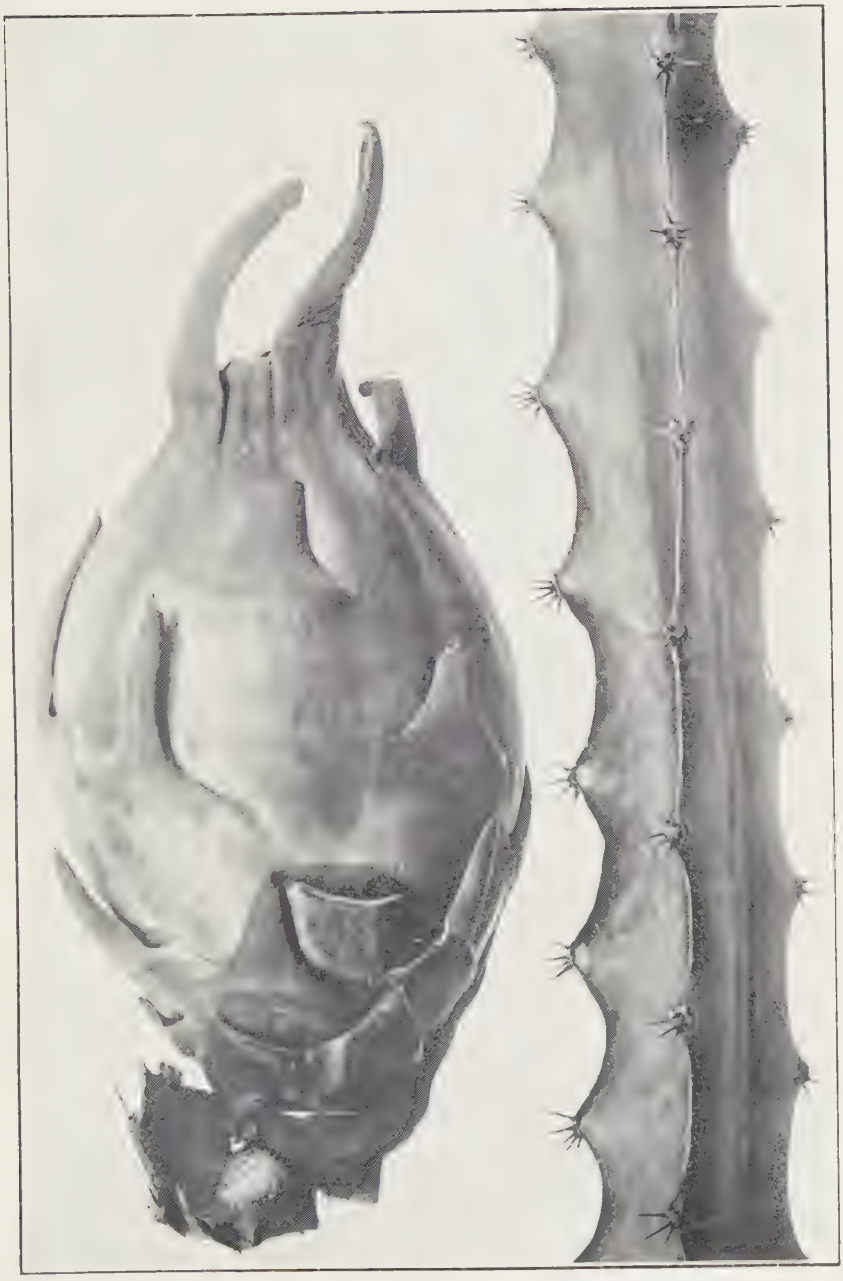
> Pitahaya is a fruit of the size of a closed fist, more or less, and this is the common size. It is borne on certain very spiny and strange-looking thistles, which are leafless but have a few branches or long arms which take the place of branches and leaves. These are four angled and longer, each branch or arm, than the arm length of a man; and between angle and angle a groove, and on all these angles and grooves at intervals are borne certain sharp and pointed spines as long as half the middle finger of the hand or more, arranged three by three or four by four; and among these leaves or branches, such as I have

described is borne this fruit called "pitahaya," which is very red, like rosy crimson, and the name signifies "scales on the rind," though they are not such; and it has a thick skin, and this when cut with a knife (which is done easily) is full of little seeds within, like a fig; but they are mixed with a paste or pulp which, together with the seeds, is of a fine crimson color; and the whole mixture, seeds and all, is eaten, and whatever it touches remains as red as though touched by mulberries, and even more so. The fruit is wholesome and is relished by many, but I should prefer many others to it. It affects the urine the same as tunas, though not so quickly, but two hours after two or three of them are eaten the urine appears like blood itself. It is not a bad fruit nor harmful, and appears well to the sight. The thistles on which these pitahayas are borne are an obnoxious thing, and of much strangeness their forms, the which are green and the spines gray or whitish, and the fruit red, as I have said, and as I have drawn it (pl. 3, fig. 3). In removing a pitahaya from where it grows one must not be in a hurry, nor be without caution and a good knife, because those thistles are close together, crowded, and many, and very well armed. Other pitahayas there be, which differ neither more nor less from the ones I have described, together with their thistles, in any manner or in taste, but only in color; because these others are yellow and what is within them is white, which is eaten, and the little seeds are black, and they do not cause any change in the urine. I have made ink of the first kind and written with it, and it is of excellent color, between purple and bright crimson.[a]

The identity of the plant described by Oviedo has not been established. It may possibly be the variable *Acanthocereus pentagonus*. The accompanying figure (pl. 12) is a photograph by Mr. G. N. Collins of a plant growing on the island of Porto Rico. It corresponds perfectly with Plumier's plate 200, figure 2, on which Haworth founded the species *Cereus trigonus*, and differs from Oviedo's plant in the shortness of the spines and in other respects. The branches of the species here figured are sometimes triangular and sometimes quadrangular. The fruit is rose-colored on the surface and it is filled with white, agreeable-tasting pulp surrounding the numerous small black seeds.[b] *Hylocereus trigonus* is characterized by salient points on the ribs, which bear the areolæ. In *H. triangularis* the areolæ are situated in the notches of crenations. Closely allied to the latter species is a triangular cereus growing on the garden walls of the city of Guadalajara, recently described by M. Robert Roland Gosselin under the name *Cereus tricostatus* (pl. 6, fig. 1). This plant is characterized by its sharp, thin ribs, which are prominently gibbous between the areoles. The spines are quite small and few in number, sometimes only two, or even solitary. The fruit is sold in the market of Guadalajara, both fresh and dried, under the name pitahaya.

[a] Oviedo. Hist. Gen. y Nat. de las Indias, lib. 8, Cap. 26, pl. 3, fig. 9. 1535. Ed. of José Amador de los Rios, p. 311. 1851.

[b] See Cook and Collins. The Economic Plants of Porto Rico. Contr. U. S. National Herbarium, vol. 7, p. 112, pl. 25. 1903.



HYLOCEREUS TRIGONUS (HAW.) N. COM.

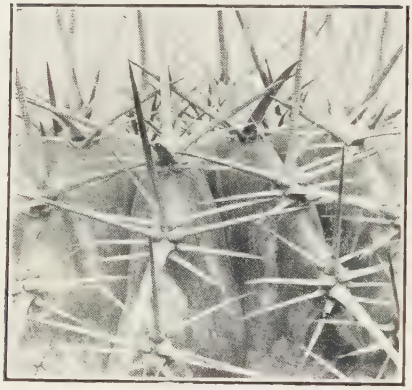


FIG. 1.—Echinocactus palmeri.

FIG. 2.—Echinocactus bicolor.

FIG. 3.—Echinocactus hexaedrocephorus.

FIG. 4.—E. (Astrophytum) ornatus.

FIG. 5.—Echinocactus pringlei.

FIG. 6.—Echinocactus cornigerus.

TYPES OF ECHINOCACTI.

The pitahayas of *Carnegiea gigantea* of Arizona and northern Sonora were noticed as early as 1540 by the members of Coronado's expedition. They are not spiny, like the fruits of Pachycereus, and they burst open when ripe. The pitahaya dulce (*Lemaireocereus thurberi*) is much sweeter and is covered with stout spines, which grow in clusters from little tufts of wool. Another columnar cactus with spiny pitahayas is *Cereus queretarensis* of southern Jalisco, Queretaro, and Guanajuato. The most important edible pitahaya of central and southern Mexico is *Lemaireocereus griseus* (pl. 9, fig. 5), a spherical fruit bearing tufts of spines and wool, somewhat resembling the pitahaya dulce of the west coast. *Myrtillocactus geometrizans* (pl. 9, fig. 2) bears the well-known little garambullas offered for sale in the market, either fresh or dried; and in northern and central Mexico several species of Echinocereus, locally known as strawberry cacti, or "alicoches," bear delicious spiny pitayitas (pl. 9, fig. 3) highly esteemed by the natives.

FIG. 20.—Carnegiea gigantea, fruit nearly ripe.

2. *Echinocactus and its allies.*—Under the genus Echinocactus Schumann includes several groups of cacti regarded by him as subgenera. Some of them are treated by other authors as distinct genera, although there occur forms which seem intermediate between two or more of the groups. Whether or not these groups be regarded as genera, there is no doubt that by separating them from one another and calling them by their distinctive names greater facility will be found in recognizing the distinguishing characteristics of the various species and their study will be much simplified.

FIG. 21.—Echinocactus, flower.

They may be defined as fleshy plants, globular, oblong, or cylindrical in shape, with vertical or radiating ribs, or rows of vertical or spiral tubercles, which are usually armed by stout spines. The leaves are reduced to microscopic vestiges or are obsolete. The flowers spring from areoles very near those which subsequently produce the spines. The perianth tube is prolonged beyond the ovary, and is usually covered with scales, either naked or bearing tufts of wool

in their axils. The outer floral leaves are scalelike, the inner elongated and sepal-like, and the innermost like true petals. The stamens are numerous and are borne on the tube of the perianth, and the style columnar and bearing a several-rayed stigma. The fruit is usually covered with scales, and often with tufts of minute bristles, in some species surrounded about its base by a thick growth of silky wool. Some of the plants belonging here are composed for the most part of succulent pulp, which is candied and made into preserve like citron. Others possess poisonous or narcotic alkaloids, and are used as intoxicants by the Indians. In a few the fruit is edible (pl. 9, fig. 4), and several yield an abundant supply of watery sap, which, though insipid, yields a grateful drink to the thirsty traveler.

FIG. 22.—Echinocactus, fruit.

The principal divisions of the Echinocacti, including Mexican species, are the following:

Cephalocactus, including the great viznagas, *Echinocactus palmeri* (pl. 8) and *E. wislizeni*, from which sweetmeats are made: *E. horizonthalonius* (pl. 2, fig. 5), *E. bicolor* (pl. 13, fig. 2), *E. pilosus*, and the closely allied crimson-spined *E. pringlei* (pl. 13, fig. 3).

Lophophora, represented by the single species *Lophophora williamsii*, the narcotic peyote, or mescal button of the Indians (pl. 3, fig. 5).

Astrophytum, or "starfish cactus," including the spineless "bishop's cap" (*Astrophytum myriostigma*), *A. capricornus* (pl. 5, fig. 2), and *A. ornatum* (pl. 13, fig. 4).

Euechinocactus, or Echinocactus proper, including *E. pottsii* and *E. electracanthus.*

Ancistrocactus, or hook-spined Echinocactus, divided into two sections, the first composed of species having wiry spines, bent like fishhooks, including *Echinocactus longihamatus* (pl. 9, fig. 4), the closely allied *E. uncinatus*, and *E. brevihamatus* (pl. 3, fig. 3); the second with dilated horn-like spines, often flattened on the upper side, annulated or transversely ribbed and curved near the tip, including *Echinocactus cornigerus* (pl. 13, fig. 6), *E. texensis* (pl. 2, fig. 1), *E. emoryi*,[a] and *E. wislizeni* of Arizona.

Stenocactus, including *Echinocactus multicostatus* (pl. 4, fig. 3) and its allies (pl. 4, fig. 5), and *E. coptonogonus.*

[a] For an illustration of an Indian drinking the sap of *Echinocactus emoryi*, see Coville, Frederick Vernon "Desert plants as a source of drinking water." Smithsonian Rep. for 1903, pp. 499–505. 1904.

Thelocactus, with the surface covered with tubercles more or less confluent, as in *Echinocactus lophothele* (pl. 3, fig. 1) and *E. rinconadensis*, or 5 or 6 sided, as in *E. hexaedrophorus* (pl. 13, fig. 5).

3. *Leuchtenbergia.*—This genus, which is represented by a single species, *L. principis*, stands quite alone among the Cactaceæ. It has a woody stem bearing long prismatic tubercles very much like those of certain Mamillarias, but the flower has a scaly tube more like that found in the genus Echinocactus. The tubercles are arranged spirally and are at length deciduous, their bases leaving the stem scarred very much like that of a Zamia after its leaves have fallen. The areoles, situated at the tips of the tubercles, are cottony or woolly when young and bear a tuft of flexible papery or strawlike spines, The large axillary brownish-yellow fragrant flowers appear from among the young tubercles near the crest of the plant. The stamens are numerous, the outer ones growing together and connate with the tube of the perianth, which they close, their upper parts free and closely fascicled around the style, which exceeds them slightly in length, bearing a 10–14-rayed bright yellow stigma. This species is used by the Mexicans as a remedy for certain diseases of animals, and at one time was gathered in such quantities as to threaten its extinction. It has been collected in the vicinity of Pachuca, Hidalgo; southeast of San Luis Potosi; and in the vicinity of Patagallina, southeast of Parras, Coahuila.

FIG. 23.—Leuchtenbergia principis.

4. *Cactus* (*Melocactus*).—The plants of this genus, often called turk's-cap or turk's-head, are fleshy and globose, or oval, usually ribbed like a melon and bearing tufts of rigid spines very much like those of an Echinocactus. It differs, however, from that genus in having a distinct cylindrical cap, or cephalium, composed of woolly felt and fine bristles, from which issue the numerous small inconspicuous flowers and at length the fruit. The latter is red, smooth, and club shaped, very closely resembling the chilitos of certain Mamillarias, and, like them, pleasantly acidulous and edible. The genus is principally West Indian and tropical American. A photograph of *Cactus maxonii* (*Melocactus maxonii* Gürke), showing a single fruit and several flowers, is reproduced on plate 2, figure 2.

5. *Phyllocactus.*—This genus is epiphytal. It has leaflike joints and beautiful, large, elongated flowers, which, unlike those of Epiphyllum, are perfectly regular and funnel shaped, with separate stamens growing from the tube and not connate at the base. The fruit is red, scaly, or marked with the scars left by deciduous scales. That of *Phyllocactus anguliger*, which grows on the slopes of the volcano of Colima, is called "pitayita del cerro," and is used in preparing a refreshing drink like lemonade. The flower of this species is tinted from flesh color to white. Another species with scarlet flowers (*Phyllocactus ackermanni*) is widely cultivated in Mexico.

FIG. 24.—Phyllocactus phyllanthoides.

6. *Epiphyllum.*—The flowers of this genus are distinctly irregular, or zygomorphic, and curved; stamens grouped in two series, the inner group of 10 stamens growing together at the base so as to form a tube. The stems are flat and jointed, the joints articulating somewhat like the segments of a crab's claws. The only well-defined species is the "crab cactus," *Epiphyllum truncatum*, from Brazil, widely cultivated in conservatories for its beautiful crimson flowers, which, instead of growing from the margin of the joints as in Phyllocactus, are terminal.

7. *Rhipsalis.*—Of this epiphytal genus, which is distinguished among all the Cactaceæ as the only one occurring spontaneously in the Old World, I have already spoken (see fig. 1, p. 537). In the island of Ceylon *Rhipsalis cassytha* is called "mistletoe" by the English residents, on account of its habit of growth and its small, pellucid, glutinous berries.

Tribe Mamillarieæ.

8. *Mamillaria and its allies.*—The plants of this genus are usually spehrical, hemispherical, or cylindrical in form and covered with wartlike or teatlike tubercles, usually arranged in regular spirals and

terminating in small spine-bearing areoles. The spines vary greatly in form, occurring in radiating starlike groups, with or without a central spine, pectinate or comblike, or long and wiry. In some species they are as fine as hairs, in others they are stout and clawlike; some are straight, others curved like fishhooks; some are smooth, others hairy, and others plumose or feathery. They are divided by Schumann into four groups: (1) Coryphantha, in which the flowers issue from near the center or apex of the plant and the tubercles have a longitudinal groove uniting the flower-bearing and spine-bearing areoles; (2) Dolicothele, in which the tubercles are long and ungrooved and the flowers issue from the axis of the tubercles; (3) Cochemiea, occurring on the peninsula of Lower California and in Chihuahua; and (4) Eumamillaria, or Mamillaria proper. These are usually regarded as subgenera, but they may be worthy of generic rank.

(1) Coryphantha is divided into two series: Aulicothelæ, in which the tubercles are without glands, as in *Mamillaria durangensis*, *M. macromeris*, *M. scheerii*, *M. elephantidens* (pl. 14, fig. 3), *M. conoidea* (pl. 14, fig. 1); and Glanduliferæ, in which circular red or yellow glands are present in the axils of the tubercles or under the areoles, including *Mamillaria macrothele* and *M. erecta*.

(2) Dolicothele, with comparatively large yellow flowers and bristlelike or needlelike spines radiating from the terminal areole of the long tubercle, is composed of the two species *Mamillaria sphærica*, of Texas, and the closely allied *M. longimamma* of Mexico (pl. 14, fig. 2), both of which contain poisonous alkaloids.

(3) Cochemiea, characterized by large flowers with exserted stamens, is represented in northern Mexico by the single species *Mamillaria senilis*, with many white, bristle like radial spines and several dark-colored hooked central spines, and with large orange-colored flowers, occurs amid the snow of the high mountains of Chihuahua. *M. roseana* occurs at La Paz and on Carmen Island, where it was collected by Dr. Edward Palmer; and *M. pondii* on Cedros Island, where it was collected by Lieut. Charles F. Pond, U. S. Navy.

(4) *Eumamillaria*.—This division is composed of two groups, the first including plants with watery sap, called by Schumann "Hydrochylus," the second with plants containing milky or gummy latex, called "Galactochylus."

Among the species included in the section Hydrochylus are *Mamillaria micromeris*, *M. greggii* (pl. 4, fig. 1), *M. leona* (pl. 2, fig. 3), *M. candida*, *M. pusilla* (pl. 2, fig. 4), *M. bocasana* (pl. 4, fig. 4), *M. glochidata*, *M. plumosa* (pl. 3, fig. 6), and *M. grahamii*, *M. carretii* (pl. 4, fig. 2).

Among the species included in the section Galactochylus are *Mamillaria elegans*, *M. celsiana*, *M. heyderi* (pl. 9, fig. 1), *M. melanocentra*,

M. gigantea, *M. heesiana* (pl. 7), *M. centricirrha*, *M. meiacantha*, *M. uncinata*, *M. sempervivi*, *M. caput-medusæ*, *M. formosa*, *M. karwinskiana* (pl. 14, fig. 4), and *M. mutabilis*.

9. *Pelecyphora*.—Only two species of this interesting genus are thus far known. They are very small plants, globular, hemispherical, or club shaped in form, and covered with peculiar laterally compressed tubercles having a very long, narrow areola, bordered on each side by a row of short appressed comblike spines. *Pelecyphora aselliformis*, usually growing in clusters (pl. 14, fig. 6), derives its specific name from the resemblance of its tubercles to the ventral surface of certain isopods, or sow bugs (Aselli). Specimens were collected by Dr. Edward Palmer in May, 1905, at Zapotillo, 12 miles east of the city of San Luis Potosi, where the plants are sold in the drug market under the name of "peote," "peyote," or "peotillo." Another locality where they are found, and which takes its name from them, is the Hacienda de Peotillas, a station on the Central Railway, which connects San Luis Potosi with Tampico. One of the specimens collected by Doctor Palmer bloomed after it had been gathered. The flower is comparatively large and of a magenta or crimson-purple color, with the outer petals rose-colored and paler on the margin, and the outermost sepallike, narrowly linear and greenish white. The stamens are only about one-third the length of the petals; they have white filaments and orange-colored anthers, beyond which the pistil projects with its greenish-yellow 4-rayed stigma.

Pelecyphora pectinata (pl. 14, fig. 5), the other species, which is here figured for the first time, is a beautiful little plant represented in the cactus house of the United States Department of Agriculture by specimens collected by Dr. J. N. Rose in 1905, in the State of Puebla. It is smaller than *P. aselliformis*, spherical at first, but at length cylindrical. Unlike *P. aselliformis* it has milky juice and yellow flowers, and is solitary. Its minute white spines are pectinate, very much like those of certain species of Echinocereus and Mamillaria, and so closely crowded that they interlace. Plate 14, figure 5, shows a young plant of this species enlarged 6 diameters.

10. *Ariocarpus*.—This genus, called by Lemaire "Anhalonium," is composed of several species of low top-shaped plants with large taproots surmounted by a rosette of more or less leaflike tubercles. These are made up of two parts corresponding roughly to the blade and claw of certain petals. The lower portion, or claw, is flattened and appressed along the stem of the plant; the upper part, or blade, is turned outward and consists of a more or less pyramidal body, the upper face of which is somewhat triangular in outline. The entire surface of this blade is covered with a cartilaginous coat, which, together with the absence of spines, distinguishes this genus from the

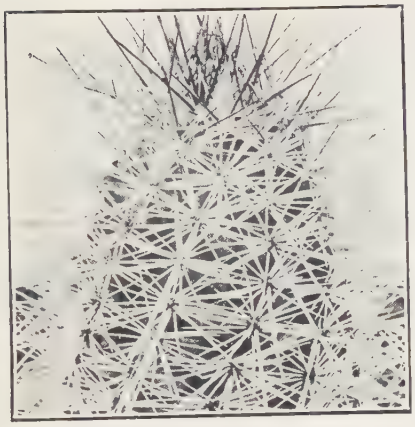


FIG. 1.—Mamillaria conoidea.

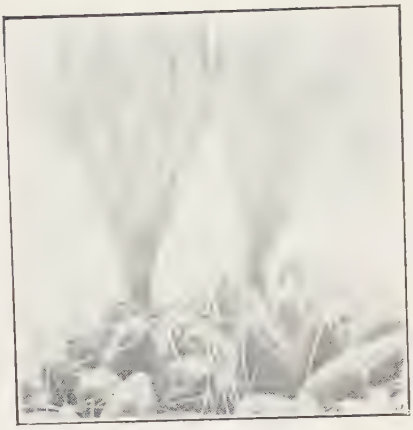


FIG. 2.—Mamillaria longimamma.

FIG. 3.—M. (Coryphantha) elephantidens.

FIG. 4.—Mamillaria karwinskiana.

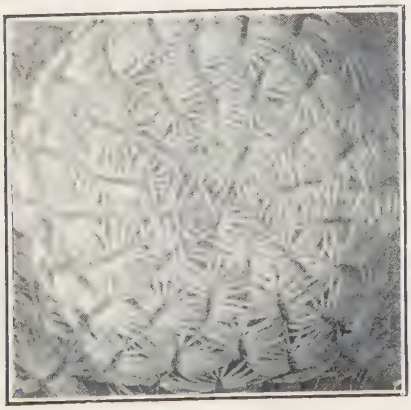


FIG. 5.—Pelecyphora pectinata (enlarged 6 diameters).

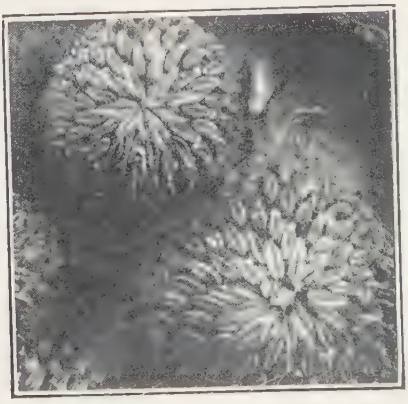


FIG. 6.—Pelecyphora aselliformis (slightly reduced).

TYPES OF MAMILLARIA AND PELECYPHORA.

ANGLER FISHES: THEIR KINDS AND WAYS.

By Theodore Gill.

If I should begin but to name the several sorts of strange fish . . . that run into the sea, I might beget wonder in you, or unbelief, or both; and yet I will venture to tell you . . . . Izaak Walton (apropos of the Common Angler), Compleat Angler, chap. 19.

Generalities.

It is generally assumed that the capture of fishes by means of a lure originated only when man had acquired a certain stage of intelligence, but, countless myriads of years before man was born, the art had been developed among animals of a much lower class—fishes themselves. Such animals are still existent and manifest under considerable variety and in many species. The largest and best known of the kind is the common fish especially known as the "angler." This name was first used for it by Thomas Pennant in 1776, and has proved to be very acceptable to most persons, but it is not entirely applicable to the fish. The word angle is primarily connected with the curved hook which is the chief agent in the capture of a fish, but the angler fish has no hook. It has a rod and a bait, but it needs no hook, for the bait attracts a victim sufficiently near to be seized upon by a sudden leap of the angler. The advantage is thus given by kindly nature to the ever-ready fish. No renewal of the bait is necessary, for the angler does not wait till the approaching little fish has time to nibble; no elaborate preparation of rod, line, hook, and bait are needed, for the fish is always prepared; not time and labor, such as taking the capture off the hook, carrying it a long distance, and various details of making ready for eating, are required, for all such actions are rendered unnecessary by the capacity to take and ingest in one continuous process.

The angler, so named by Pennant and so called by all ichthyologists since, is the only one of its kind frequenting the shallow seas of northern Europe and northern America, but it is only one of a numerous group. That group, however, is represented by species

inhabiting the deep seas of almost all parts of the globe, as well as by numerous species lurking in tropical coral groves, and in the sargasso meadows of the high seas. The group is distinguished by so many peculiar characters that it is ranked as an order or suborder by all modern ichthyologists under the name of Pediculati or Pediculates. The name is primarily due to Cuvier, who gave the form Acanthopterygiens a pectorales pédiculées, or, for short, Pec-

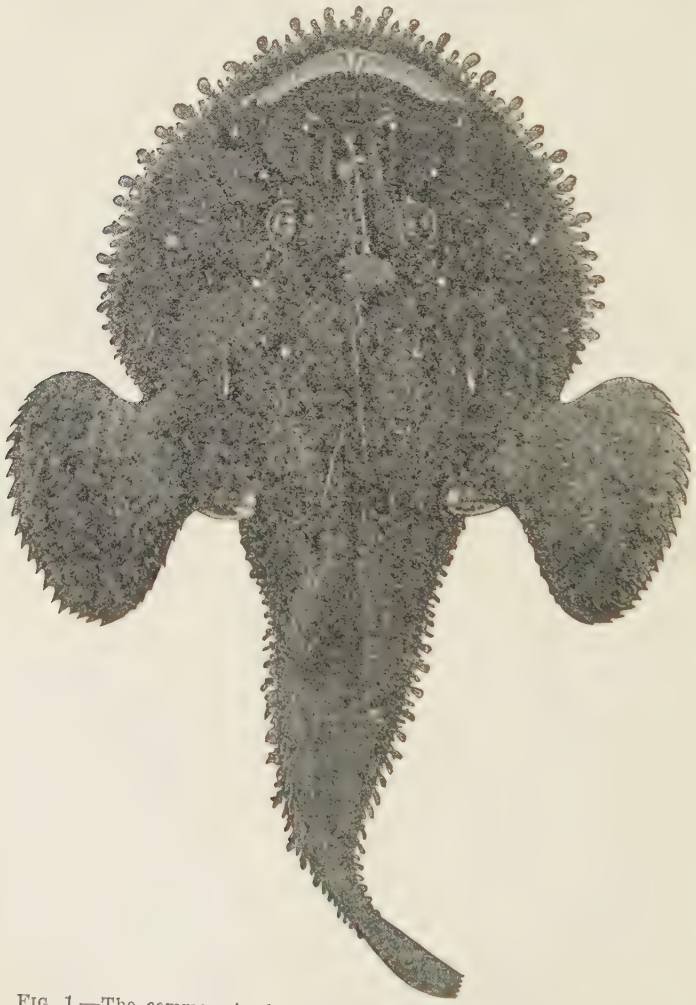


FIG. 1.—The common Angler (*Lophius piscatorius*). After Smitt.

torales pédiculées as a family designation. This was latinized as Pediculati and subsequently used as a subordinal and still later as an ordinal term. With the last sense it is here used. The old authors mostly associated with the Pediculates, the Batrachoidids, or Toadfishes, and they have been restored to the order by Regan (1909), but not by other authors, nor in the present article.

PART I.

Order Pediculati.

The Pediculates are teleost fishes, offshoots from the Acanthopterygians, or spine-finned fishes, and have a closed air bladder, if any, the scapular arch connected with the sides of the skull, the mesocoracoid bone absent, the actinosts in reduced number (2 or 3) and in typical form elongated to form false arms, or pseudobrachia, and the

Fig. 2.—Shoulder girdle of the Angler, showing the pseudobrachium or false arm with its two actinosts (*a*), the hypercoracoid (*hr*), hypocoracoid (*ho*), and postscapula (*ps*), as well as proscapula or cœnosteon (*c*). After Mettenheimer.

ventrals advanced forward; the ventrals, when present, are indeed jugular; the skull is depressed and without a myodome or cavity for the insertion of the ocular muscles, the parietals are separate and thrown to the sides by the intervention and contact of the supraoccipital and frontals, and the suborbital chain of bones is absent. The vertebral centra are well developed and separate, but there are neither ribs nor epipleurals. The branchial apertures are much reduced and manifest as foramina in or about the axils of the pectorals, generally the upper axils, sometimes the lower.

Fishes having these characters in common exhibit great diversity in other respects, and not least in the provision for alluring other fishes. They have, however, been mainly associated on account of agreement in other characters. The most essential of these are the position of the branchial apertures, the direction of the mouth, whether opening upward or downward, the number of bones (actinosts) in the false arms (pseudobrachia) that bear the pectoral fins, the development of the first dorsal, and the presence or absence of ventral fins. There are six groups which are so trenchantly distinguished by modifications or combinations of these characters as to have secured from ichthyologists family designations. Their mutual relations may be best exhibited in a synoptical table:

PEDICULATE FAMILIES.

I. Branchial apertures about (in or behind) the inferior axils of the pectorals; opercular bones moderately or little developed.
   (*a*) False arms with 2 actinosts; pectorals scarcely geniculated; body depressed; hypapophyses appressed (*Lophioidea*) *Lophiidæ*.
   (*b*) False arms with 3 actinosts; pectorals strongly geniculated; body compressed or tumid; hypapohyses erect (*Antennaroidea*) *Antennariidæ*.

2. Ventrals lost. (*Ceratioidea.*)
   (*a*) Mouth large, directed upward; snout flat behind and rostral spine erect ---------- *Ceratiidæ*.
   (*b*) Mouth large, directed downward; snout procurrent and rostral tentacle at end and horizontal ---------- *Gigantactinidæ*.
   (*c*) Mouth small, terminal, and nearly horizontal; snout blunt and destitute of tentacle ---------- *Aocratiidæ*.

II. Branchial apertures about superior axiis of pectorals; opercular bones greatly developed; ventrals developed; false arms with 2 actinosts; mouth inferior; rostral tentacle inferior or terminal, sometimes atrophied (*Ogcocephaloidea*) ---------- *Ogcocephalidæ*.

Almost all the Pediculates have the foremost spine advanced forward near or on the snout and modified to serve as a lure for other fishes; it has been likened to an angler's rod with its line and bait, and this fancy has been carried out in the names given to the apparatus. S. J. Garman, in his fine work on "The fishes" of A. Agassiz's Reports of an Exploration off the West Coast of Mexico, etc. (1899), has designated as the "illicium" or "bait and rod" the foremost dorsal spine with its leaflike appendage, and further distinguished the "bait" as the "esca." These are developed with various modifications in the Pediculates that live in the shallow or less deep seas, and undoubtedly the illicium and esca actually serve as a rod and bait, but, of course, the fish so provided does not knowingly act as an angler, for its action is merely automatic. The modification of the spine doubtless originated in a fortuitous manner and its use to the

fish was such that it, and its progeny so favored, survived the "struggle for existence" and, through the slight useful modifications supervening, the specialized illicium and esca of the modern fishes became perfected. But this was not all.

Some stout-bodied Pediculates resorted to deep and deeper waters, where the light from the sun was faint or even ceased, and a wonderful provision was at last developed by kindly nature which replaced the sun's rays by some reflected from the fish itself. In fact the illicium has developed into a rod with a bulb having a phosphorescent terminal portion and the "bait" round it has been also modified and variously added to; the fish has also had superadded to its fishing apparatus a lantern (lampas) and wormlike lures galore. How efficient such an apparatus must be in the dark depths where these angler fishes dwell may be judged from the fact that special laws have been enacted in some countries against the use of torches and other lights for night fishing because of their deadly attractiveness. Not only the curiosity of the little deep-sea fishes but their appetite is appealed to by the wormlike objects close to or in relief against the phosphorescent bulb of the anglers.

Only a few of the many varieties of the torch-bearing anglers need be noticed here. They all occur in the family of deep-sea Pediculates known as the "Ceratiids."

Generally the interspinal bone is directed forward and mostly concealed, and the articulating spine or rod extends upward; the terminal portion of the spine is provided with a bulbiform apparatus, with a luminiferous terminal surface and various appendages in relief against it. Often the appendages are curiously developed, sometimes filiform and simple, as in *Ceratias;* sometimes papilliform and numerous, as in *Melanocetus.* Occasionally the rod is very stout and the wormlike appendages numerous and manifest on the rod as well as around the bulb; in the *Himantolophi* of the Atlantic and Pacific (Japan) the furniture is carried to an extreme.

Rarely the interspinal bone appears to be exserted and prolonged and the spine or rod articulated a long distance from the back, as in *Mancalias.*

A few other Pediculates (the *Gigantactis* is the only one known) with a slender body developed in another direction. The illicium and snout conjoined extended far forward in a horizontal direction.

All the Pediculates till now considered have the first dorsal spine really dorsal, or at least rostral. Now we may take notice of some that reverse the usual order of nature. This reversal is manifested in the family of Ogcocephalids (better known as *Malthids*).

Not uncommon along the southern coasts are certain fishes of this family, inhabiting shallow waters with a sandy bottom. They are of toad-like appearance, and rest on their arms as a toad does on its hind legs, while the fins are far in advance and assume the function of fore

feet. Though like toads, the fishes are generally known to the people not only as "toads" but also as "sea bats" on account of the appearance they present in the water, and this name has been perpetuated in the scientific designation of the longest known species—the *Malthe vespertilio*.

The reversal in the attitude and position of the members, whereby what are usually the fore limbs become the hind and the hind limbs the foremost, is not the only case of contrariety. The dorsal has become lowermost and by a remarkable growth. The anterior spine had advanced forward on the snout; then the forehead had grown out into a long projection which forced the snout with the dorsal spine downward, thus reversing its direction. Still more, the dorsal spine—spine only in name, however—had lost, or perhaps never developed, the function of rod and line, and has apparently assumed a tactile function. It has a papilliform tip, and doubtless by means of it feels for its food.

The few species of *Malthe* and one of *Halieutæa* are the only representatives of the family that are inhabitants of the shallow waters. There are many other species, but they are deep-water forms.

The Malthids, indeed, are a numerous family of deep-loving fishes, and every expedition for the exploration of the deep sea brings back new forms. These exhibit considerable difference in the development of the subrostral or rostral tentacle, and in some the tentacle is obsolete. None, however, have the tentacle developed as in *Malthe*, and no others have the projecting forehead or the downward trend of the tentacle. In all others the rostral cavity is open forward, and perhaps the tentacle may serve as a lure, as in the Pediculates generally. That it is not a very efficient organ is apparently indicated by its obsolescence in some of the species.

One remarkable characteristic of the Pediculates, so far as known, is the provision made for the eggs. The oviposition of only two species is known, it is true, but those two being of widely distinct families—the Lophiids and Antennariids—it is probable that what is true for them is true for all others of the same families. The two species in question are the common angler (*Lophius piscatorius*) and the frog-fish (*Pterophryne histrio*). These agree in having paired ovaries in which are developed eggs so connected that, when emitted, they are enveloped in a glutinous secretion reflecting the form and structure of the ovaries but, on contact with the water, become immensely distended and form buoyant raft-like receptacles which float at or near the surface till the eggs are hatched. The rafts are swollen to an enormous size in comparison with the mother fishes, those of the common angler sometimes reaching a length of 36 feet and those of the frog-fish a couple of feet.

Whether the Pediculates of other families agree with the Lophiids and Antennariids is doubtful and a subject for future investigation.

A most remarkable episode is connected with the history of the Antennariids. In 1872 the illustrious Professor Agassiz obtained a globular mass of sea-weed (*Sargassum*) charged with eggs, and assumed that the mass was a nest made by a frog-fish, and for a gene-

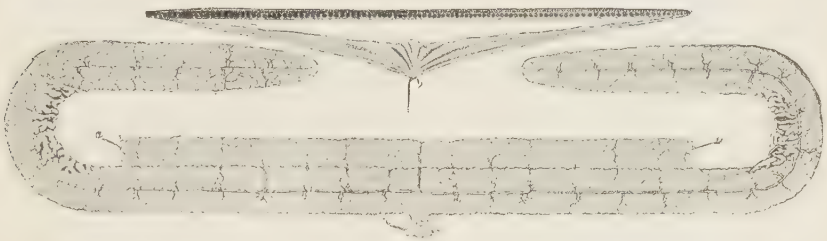


FIG. 3.—Ovaries of the common Angler (*Lophius piscatorius*). After Fulton (reduced).

ration or more his view was unhesitatingly adopted. It was only after the discovery of the actual oviposition of the frog-fish that suspicion was attached to the old identification. As will appear from the third part of this article, the Sargassum conglomeration is due to the peculiar eggs of a flying-fish.

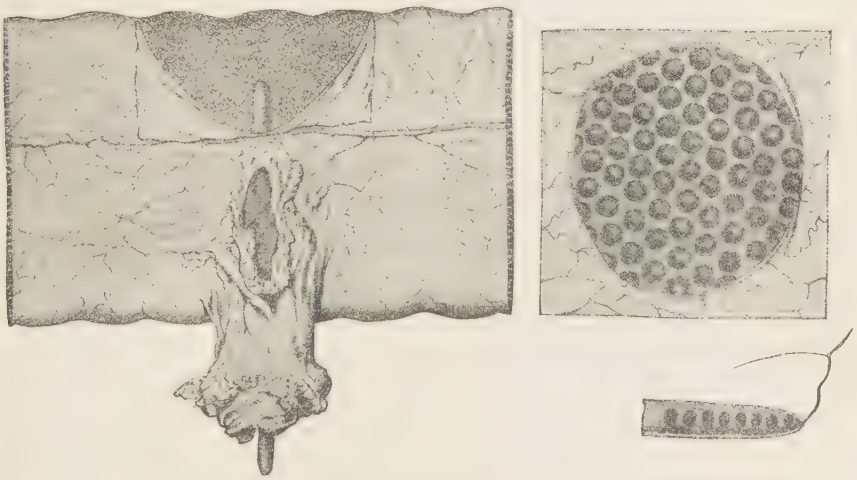


FIG. 4.—Enlarged view of ovaries and ova of the common Angler (*Lophius piscatorius*). After Fulton.

The *Sladenia* is especially noteworthy as being a less depressed form than others of its family as well as on account of the difference in the connection of the spines and rays.

EARLY PEDICULATES.

It might naturally be supposed that fishes so eccentric in their organization as the Pediculates came into existence at a comparatively late period in the development of animal life. It is there-

fore remarkable that typical representatives of the order have left evidences of earlier existence than most modern types. Near the commencement of the Tertiary epoch, in the sea which then covered an area which is now surmounted by Mount Bolca in northern Italy, an Antennariid laid wait for its prey, which consisted largely of animals very different from any now living. So closely related, indeed, was that Antennariid to living forms that it can scarcely be distinguished generically from the species of *Pterophryne*, which is now represented in almost all tropical and subtropical and even temperate seas where the sargasso weed flourishes or is carried by currents and winds; its relationship and characteristics were, however, long misunderstood, and consequently it was isolated as a peculiar generic type—*Histionotophorus*—without knowledge of its relationship or distinctive characters. Contemporary with the Antennariid, as well as a cotenant of the same sea, was an angler that

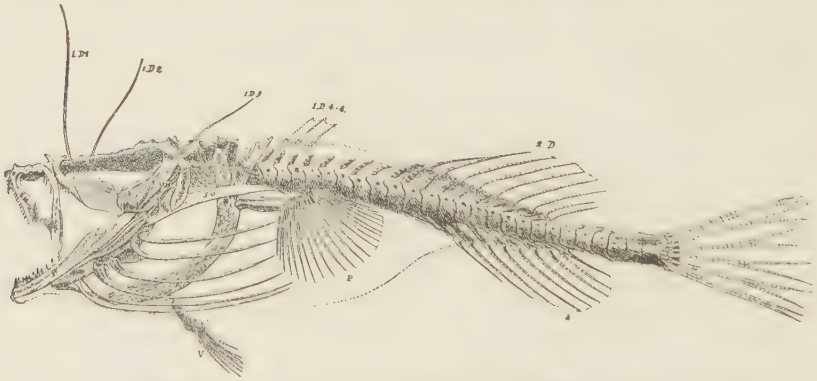


FIG. 5.—Skeleton of the Angler (*Lophius piscatorius*). After Agassiz.

no one has ever attempted to differentiate generically from the common angler (*Lophius piscatorius*) of the present northern Atlantic;[a] *Lophius brachysomus* is the universally accepted name of the Eocene angler.

THE FAMILIES OF PEDICULATES.

THE LOPHIIDS.

The Lophioid family is represented by the largest and best known of the Pediculates, the angler of the books, better known to the shoremen of the New England States as the "goose fish" and to those of old England as the "fishing frog," "sea devil," and by

[a] It is not intended to deny that the fossil Lophiid may be generically distinct from the *Lophius piscatorius*, for it probably was, but the generic characters of the modern forms are mostly osteological and not evident superficially. It may be that the Eocene species was more related to *Lophiomus* or even congeneric with it, for apparently it had a reduced number of vertebræ.

various other designations. It has been described at length by the present writer in "The life history of the angler," published in 1905 in the Smithsonian Miscellaneous Collections (vol. XLVII, pp. 500–506, pls. LXXIII–LXXV.). Three genera were then noticed, *Lophius*, *Lophiomus*, and *Lophiodes*[a] or *Chirolophius*. Since then a remarkable form (*Sladenia*) has been described by C. Tate Regan from the Indian Ocean ("Chagos Archipelago, Salomon") in the Transactions of the Linnean Society of London (Zool. (2), XII, p. 250, pl. 32, 1908).

Figures are here added of the side view of the body as well as remarkable ovaries of the common angler and its skeleton, for comparison with the egg raft of the frog fish (*Pterophryne*) and the skeleton of an Antennariid. Regan's illustration of the *Sladenia* is also reproduced.

FIG. 6.—*Lophius piscatorius*. After Goode and Bean.

THE ANTENNARIIDS.

The richest in species (but not in genera) of the families of the Pediculate fishes is that of the Antennariids. These species are mostly inhabitants of tropical coral seas of moderate depths, but a few have established homes in the midst of floating seaweed, and others in waters of considerable depth. The most characteristic and those which come most frequently in the field of observation of ordinary travelers are representatives of two genera, *Antennarius* and *Pterophryne*. The

[a] *Lophiodes* was proposed by Goode and Bean, Oceanic Ichthyology, p. 537, in 1895–96.

histories of both are remarkable, and little is known about them to most persons, for the information respecting them is widely scat-

FIG. 7.—An Angler of the Chagos archipelago (*Sladenia gardineri*). ⅛ nat size. After Regan.

tered and published in volumes not generally accessible. To bring together data so distributed, and to correct certain common errors are the objects of the present article.

FIG. 8.—Skeleton of an Antennariid (*Chaunax coloratus*). After Garman.

The family of Antennariids is segregated from all others by a combination of characters. The body and head are more or less compressed, or at least not notably depressed as in the anglers; the

mouth is cleft very obliquely and in some even vertically; the branchial apertures are in or behind the lower axis of the pectoral fins, these fins themselves are well developed and so articulated with the pseudobrachia or false arms as to form elbowlike joints, the fins being dirigible downward and forward; the pseudobrachia are formed by actinosts moderately elongated and only reduced to three on each side; the ventrals are of moderate size and provided with five (or four) rays, and the spinous dorsal is variously developed, mostly with three spines, but represented by at least a rostral tentaclelike ray. These characters are associated with various osteological peculiarities, the most notable being the development of upraised hæmal spines to most of the abdominal vertebræ.

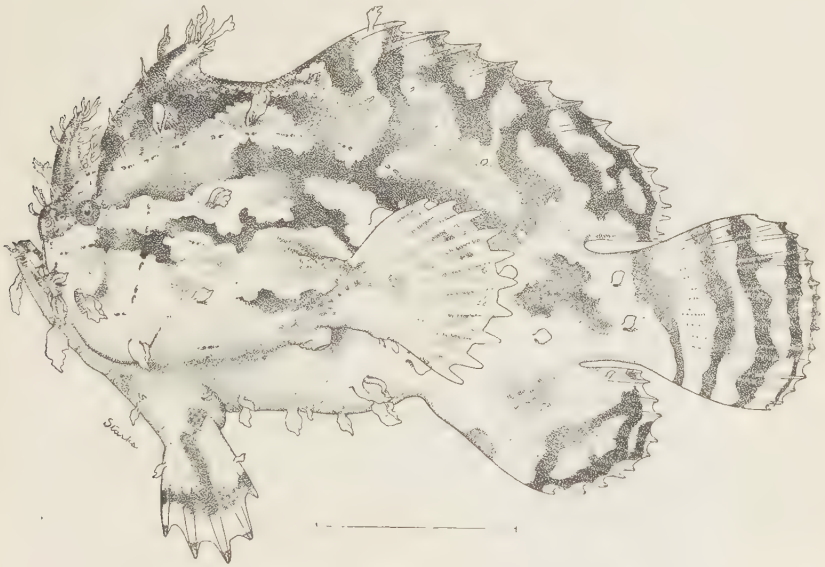


FIG. 9.—*Pterophryne histrio.* After Jordan and Sindo.

As so limited, the family embraces a dozen or more genera which represent three groups of supergeneric value, the subfamilies *Antennariinæ*, *Brachionichthyinæ*, and *Chaunacinæ*.

The two most generalized of the three groups have the body and head notably compressed, and the first dorsal fin is represented by three rays, the foremost of which is generally reduced to the form of a rostral tentacle, while the second and third are robust spines; the soft dorsal is well developed. The two groups are in their turn distinguished by well-marked characteristics.

The least specialized species have the body oblong claviform, the mouth is comparatively small, the palate unarmed, the pelvic bones are short, and the twenty or thirty dorsal rays are approximated

and well connected by membrane, so that a real fin is developed. This group is named Brachionichthyinæ, and includes two genera—*Brachionichthys* and *Sympterichthys*. Very few species are known and they have only been found as yet in Australasian seas, or, more specifically, about Tasmania.

Most of the species—until recently more than all the other Pediculates—have the body oval with a tumid abdomen; the mouth is quite large, and the palate dentigerous; the pelvic bones are rather elongated, and the second and third dorsal spines are distant or slightly connected and not constituents of a true fin. The group or subfamily is known as the "Antennariinæ" and includes the genera *Pterophryne*, *Antennarius*, *Histiophryne*, *Saccarius*, and several others. Almost all of the species, however, belong to the genus *Antennarius*.

The most specialized of the Antennariids are trenchantly separated from the others by having the head cuboid and the first dorsal fin

FIG. 10.—A chaunacine Antennariid (*Chaunax pictus*). After Jordan and Evermann.

reduced to a single piece, developed as a rostral spine, or rather tentacle, although a second spine remains concealed under the skin; the soft dorsal fin is low. Only one genus—*Chaunax*—is known.

The most conspicuous of the Antennariids are mostly confined to the coralligenous seas, and by far the largest number belong to the genus *Antennarius*. The only other genus equally well known is *Pterophryne*, whose chief home is the sargasso meadows of the high seas. These are the only ones that need to be noticed at length; they are indeed the only ones whose habits are even tolerably well known.

THE CERATIIDS.

The family of Ceratiids, or deep-sea anglers, has been constituted for a number of deep-sea Pediculates distinguishable at once by the absence of ventral fins and the robust body. There is considerable variation in form, but most are more or less compressed, and the head

varies with the body; the mouth ranges from nearly horizontal to vertical and from moderate to great extent; the branchial apertures are behind or below the axils of the pectorals; the pectorals have abbreviated pseudobrachia with three actinosts and are not at all geniculate; the first dorsal is represented by a single ray advanced forward over the snout and "baited" with a "lure" or "bait;" in some a postcephalic spine or caruncle is developed; the second dorsal and anal are generally very short, but in some more extended and multiradiate; the caudal is quite uniform in composition, having gen-

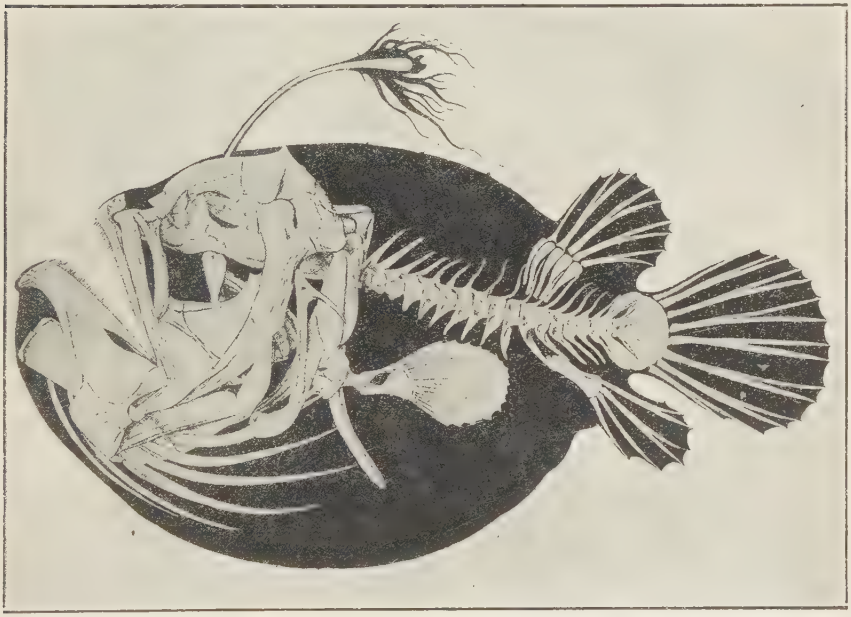


FIG. 11.—Skeleton of a himantolophine Ceratiid (*Himantolophus reinhardti*). After Lütken.

erally eight or nine rays, four or six medium rays forked, and one or two upper and one to three lower simple rays.

Much diversity is manifest in this group, extending to the compression of the head and body, the extent and direction of the mouth, the development of the dorsal and anal fins, and the modification of the rostral spine. Most have the mouth moderate and the dorsal and anal pauciradiate (D. 4, A. 4), but a few (*Melanocetines*) have a very deeply cleft mouth and pluriradiate fins (D. 14). The skin is generally naked, but in some (*Himantolophines* and *Egæonichthyines*) is beset with scattered tubercular plates. Almost all have the head compressed, but in one group (*Egæonichthyines*) it is depressed.

though otherwise that group is nearly like the *Himantolophines*. Some of the species become quite large, reaching a length of at least 28 inches, and the first *Himantolophus* found was nearly 2 feet long; most of them, however, are rather small fishes, or at least only small specimens have been secured.

The Ceratiines are the most numerous as well as typical of the family. All have a smooth or prickly skin (but no tubercles), a moderately large, vertical mouth, $2\frac{1}{2}$ pairs of gills, and a cephalic spine with a terminal bulblike apparatus, but this apparatus and the dorsal spines are manifest under various guises which mark distinct genera.

The anterior dorsal spine, or illicium, and its support are singularly modified. The support is homologous with the interspinal bone

FIG. 12.—A Ceratiine (*Ceratias holbolli*). After Kröyer and Gaimard.

intervening between the ray and the neural spine of an ordinary fish, and this may be horizontal and concealed, as in *Ceratias*, partly exposed, as in *Cryptopsaras*. In all the Ceratiines, as well as in most others of the family, the spine has a bulbous extremity, which is generally grayish at its distal end and has a filiform appendage. The light area is supposed to be phosphorescent, and thus to attract fishes in the depths sufficiently near to be seized.

In *Ceratias* the frontal spine arises above the eyes and is jointed on to a concealed horizontal interspinal bone; there is a second dorsal spine some distance in front of the dorsal fin, and there are no caruncles. The only known species, *Ceratias holbolli*, is the longest, and by far the largest, known of the group. It has been found off Greenland and Nova Scotia and attains a length of about $2\frac{1}{2}$ feet.

In *Cryptopsaras* the frontal spine is rodlike and supported by a partly exserted interspinal bone. The second dorsal spine is repre-

sented by a large median subglobular caruncle and a pair of lateral caruncles, all near the dorsal fin. The only species, *C. couesii*, was

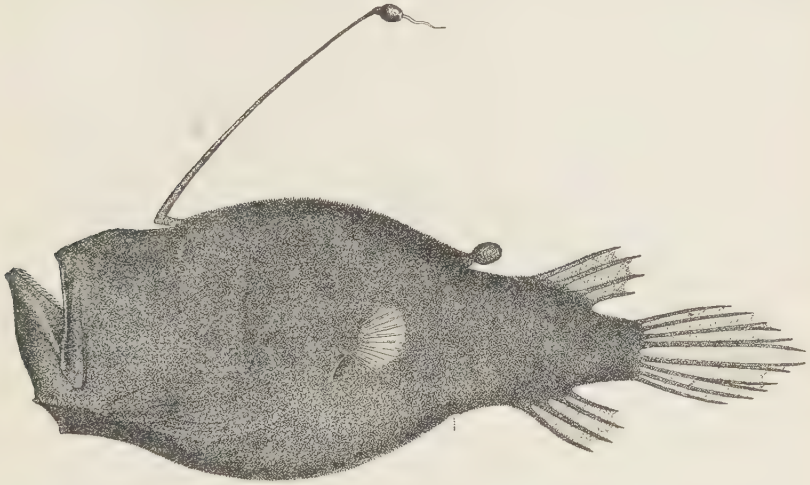


FIG. 13.—A Ceratiine (*Cryptopsaras couesii*). After Jordan and Evermann.

found in the Atlantic (lat. 38° 18′ N., long. 68° 24′ W.) at a depth of 1,686 fathoms.

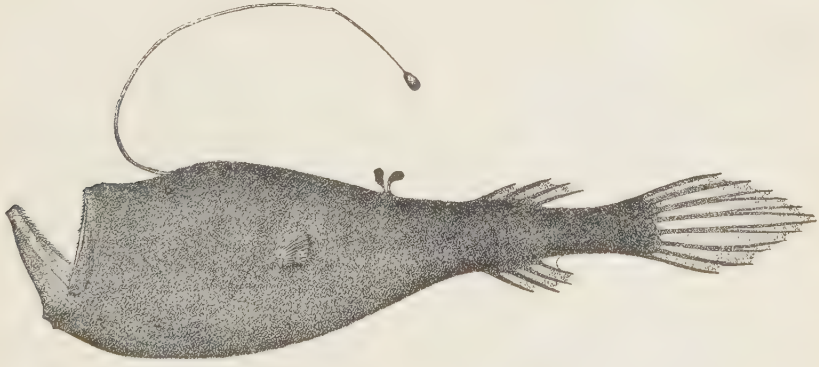


FIG. 14.—A Ceratiine (*Mancalias shufeldtii*). After Jordan and Evermann.

In *Mancalias* the frontal spine is abbreviated and supported by a long exserted rodlike interspinal. The combination reminds one of a long rod with a short line baited at the end. There is no second spine, but in its place is a pair of pedunculate caruncles. One species, *M. uranoscopus*, was originally made known from a specimen brought from a depth of 2,400 fathoms in the mid-Atlantic; another, *M. shufeldtii*, was discovered in the Atlantic not far from the American coast at a depth of 372 fathoms.

FIG. 15.—*Paroneirodes glomerosus*. After Alcock.

The Oneirodines scarcely differ from the Ceratiines and are such fishes as have the mouth less oblique or nearly horizontal and the skin smooth. They have one cephalic bulbiferous spine and one post-

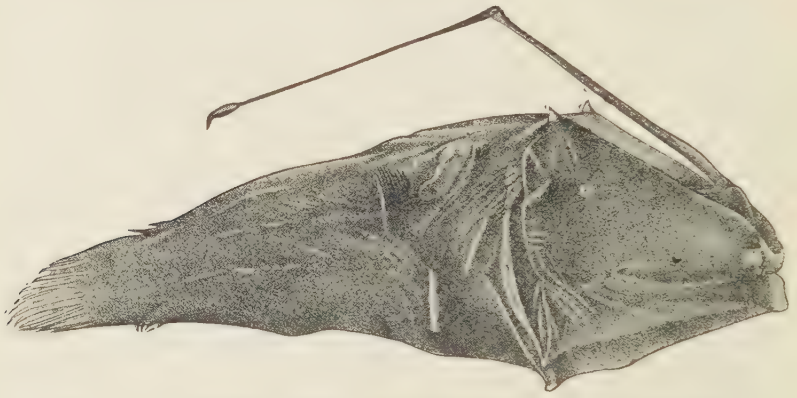


FIG. 16.—A degenerate Ceratiid (*Dolopichthys allector*). After Garman.

cephalic spine. The typical representative of the group is the *Oneirodes eschrichtii* of Greenland. Another example is the *Paroneirodes glomerosus* of the Bay of Bengal.

Another relation of the Ceratiines but differing so much from the recognized members of the subfamily as to be entitled, perhaps, to distinction as a subfamily type (*Dolopichthyines*) is the *Dolopichthys allector* of Garman. The head is much enlarged, the mouth nearly or quite horizontal, and the body behind (cauditrunk) singularly attenuated; the fins are much reduced in size and more or less enveloped in the loose skin which invests the body.

FIG. 17.—The illicium or dorso-rostral spine of Dolopa ceratiid (*Dolopichthys*). After Garman.

The Himantolophines and Ægæonichthyines agree in having a moderately cleft mouth (in comparison with other forms of the family), osseous scutellæ scattered over the body, 2 pairs of gills and half gills on first and fourth arches ($\frac{1}{2}$, 2, $\frac{1}{2}$), and a frontal spine with a bulb surrounded or surmounted by filaments. The rays of the best known forms are dorsal 5 (four forked), anal 4 (third and fourth at least forked) and caudal 8 (all except uppermost forked), but the first described species (*Himantolophus grænlandicus*) was claimed to have 9 dorsal rays;

it is possible (or even probable) that the describer may have mistaken the branches of the rays for the rays themselves.

While thus agreeing with each other the Himantolophines and Ægæonichthyines are remarkably distinguished by a difference of form so striking as to at first deceive the observer. The Himantolophines, as usual in the family, are compressed while the Ægæonichthyines are much depressed. Such a difference is entirely exceptional in a natural family and might at first prevent a recognition of the

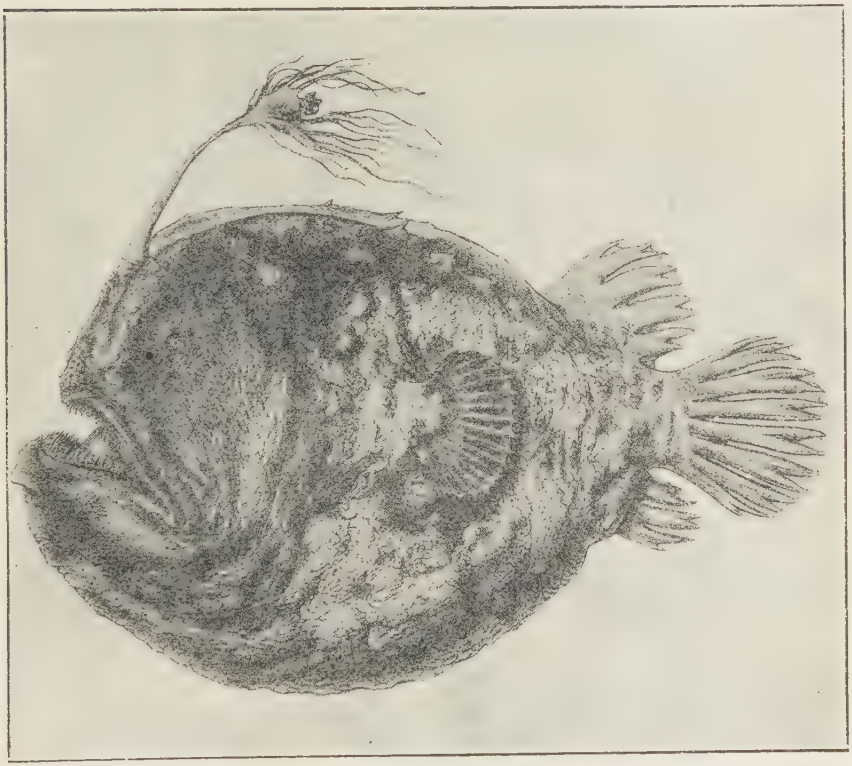


Fig. 18.—Himantolophine (*Himantolophus reinhardtii*). After Lütken.

close relationship of the two types, but further investigation must convince one that they are really nearly related.

A comparison of the typical species of Himantolophines and Ægæonichthyines shows by what slight organic changes the very different appearance of the two forms has been brought about.

In *Himantolophus* the head and body are compressed, the suspensorium of the lower jaw nearly vertical (slightly inclined forward), and the mouth cleft is normally oblique.

In *Ægæonichthys*, the head (as well as body) is exceedingly depressed, the suspensorium of the lower jaw very oblique and pushed forward, and the mouth cleft is more than vertical for it actually

FIG. 19. An Ægæonichthyine (*Ægæonichthys appelii*). After Clarke.

inclines backward, the front edge being decidedly posterior to the articulation of the jaw with the suspensorium.

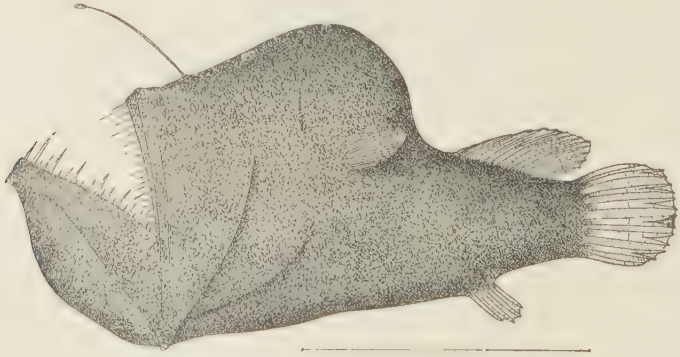


FIG. 20.—*Melanocetus johnsonii*. After Goode and Bean.

By inspection of the figure of the skeleton, it will be seen that the suspensorium and side bones are articulated with the cranium, which is compartively narrow. Now if the head and body of the *Himantolophus* should be crushed or pressed downward, the side pieces are

and the mouth would become vertical or retrocline. In other words, so connected that they would be pushed outward as well as forward

FIG. 21.—A Melanocetine (*Melanocetus krechi*). After Brauer.

without any great modification of the individual bones or parts, the

FIG. 22.—A Melanocetine (*Lioccetus murrayi*). After Günther.

remarkable differences in form between the Himantolophine and Ægæonichthyine would be produced.

The Melanocetines have, even for the family, an enormous and very deeply cleft mouth, the cleft nearly vertical, the skin smooth, and the gills developed as two complete and the last a half (2, ½).

FIG. 23.—A Linophrynine (*Linophryne lucifer*). Views from side and front. After Collett.

Several genera are known, the first discovered and the richest in species being *Melanocetus.* The typical species is the *Melanocetus Johnsonii* first found off the island of Madeira. A fish later found in the Caribbean Sea east of the Central American coast (lat. 13° 01′ 30″ N., long. 81° 25′ W.) at a depth of 992 fathoms, was identified by Goode and Bean (probably erroneously) with it; their figure (evidently of a distorted individual) is here reproduced. Another species illustrated (*Melanocetus krechi*) was obtained in the Indian Ocean off the coast of Zanzibar at a depth of 2,500 meters.

Another representative of the Melanocetinine Ceratiids was obtained by the Challenger Expedition in the mid-Atlantic at a depth of 1,850 fathoms and has been named *Liocetus Murrayi;* it differs from *Melanocetus* chiefly in the absence of vomerine teeth. A specimen was dredged later nearer the American coast from a depth of 2,450 fathoms.

As may be inferred from the size of the mouth and teeth, the Melanocetines are ravenous raptorial fishes which may sometimes seize and ingest fishes much larger than themselves. For instance,

the first specimen of *Melanocetus Johnsonii* obtained by Mr. J. G. Johnson at Madeira was less than 4 inches long (3.8 inches), but it had actually engorged a scopeloid fish about twice its own length (7½ inches). The extensibility of the jaws and connected parts as well as the dilatibility of the œsophagus, stomach, and integuments enabled the captor fish to accomplish this feat. So completely had the captor ingested (but not digested) the scopelid that "it was tempted to take a bait" and was thus secured for ichthyology.

Another group (Linophrynines) agrees essentially with the Melanocetines but are unique among the Pediculates by the development of an inferior tentacle pendent from the throat. The only species known is *Linophryne lucifer* obtained near the island of Madeira. The peculiar "gular tentacle" is quite large and terminates

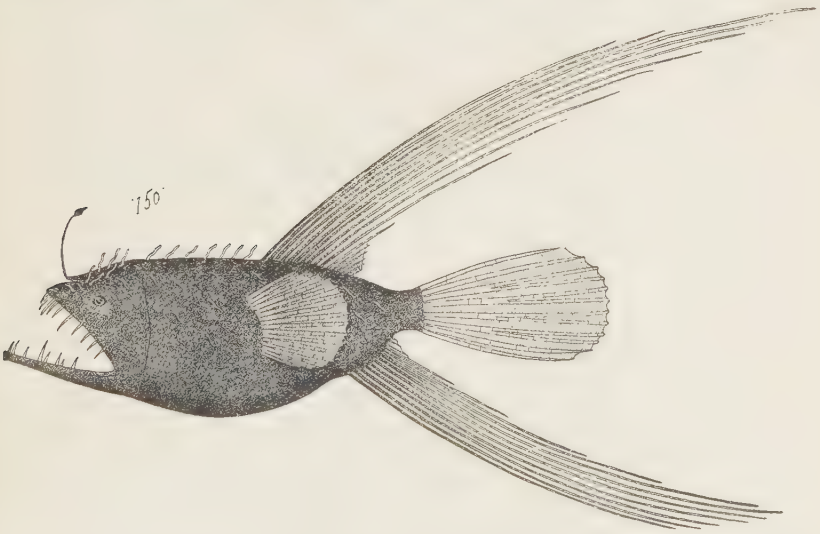


FIG. 24.—A Caulophrynine (*Caulophryne jordani*). After Jordan and Evermann.

"in two tongue-like appendages, which are furnished on the upper edge with a row of round white papillæ." Like the Melanocetines, the *Linophryne* is a bold raptorial fish and the individual which was obtained owed its capture and death to its greediness; it had seized and engorged a fish longer than itself" and consequently was carried by the gas evolved by the decomposing fish up to the surface where it was detected by a man fishing for turtles and saved for "the museum of the Christiania University."

The Caulophrynines present a combination of remarkable characters. The antepectoral region or "head" is remarkably large—even larger than the rest of the body, the mouth very deeply cleft and little oblique, and the pectoral fins are large; the dorsal and anal are not only multiradiate, but most of the rays greatly prolonged. Only

one species is known, *Caulophryne jordani*, found in the Atlantic near the American coast (lat. 30° 27′ N., long. 71° 15′ W.) at a depth of 1,276 fathoms.

THE GIGANTACTINIDS.

The family of Gigantactinids is represented by a single known species, evidently related to the Ceratiids and, like them, destitute of ventrals, but with an elongated slender body. The dorsal, anal, and caudal fins are like those of the Ceratiids. The chief distinctive character is the union of the spine or illicium with the snout and its extension forward as a long rigid rod with a terminal complex lampas and esca. The mouth is cleft in a nearly horizontal direction. The branchial apertures are infra-axillary, as in the Ceratiids.

The only species of *Gigantactis* yet found is the *G. vanhoeffeni* of A. Brauer. Two specimens were dredged, one in the Indian Ocean,

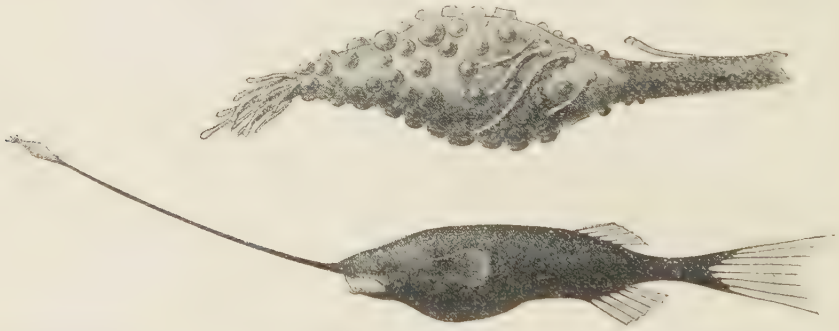


FIG. 25.—The type of the family Gigantactinids (*Gigantactis vanhoeffeni*). After Brauer.

west of the Chagos Archipelago, from a depth of about 900 fathoms (1,900 m.), and the other east of Zanzibar, from a depth of about 1,200 fathoms (2,500 m.). They were of small size, ranging in length from an inch and a quarter (3 cm.) to an inch and a half (3.5 cm), exclusive of the illicium; the latter in the largest specimen was nearly as long as the rest of the fish (3.3 cm.).

The habits of this species must be modified in accordance with its form and the extension forward of its fishing apparatus. The slender form, and especially the slender caudal peduncle and long deeply emarginate caudal fin, indicate a swift fish and one less prone to remain near the bottom of the ocean than the other Pediculates. The fish doubtless swims freely in the depths with its illicium directed forward, attracting the fishes and other organisms in the water through which it courses. A fish thus attracted is liable to be darted upon by a vigorous turn of the caudal fin and seized by the long prehensorial teeth of the angler. The entire conformation suggests a swift-moving raptorial animal.

THE ACERATIIDS.

Another family related to the Ceratiids is that of the Aceratiids, which contrasts remarkably with the Gigantactinids by the complete loss of the illicium; the family name refers to this characteristic. The body is more or less oblong or even elongate and subcylindrical, and the cephalic region smaller than in the Ceratiids. The mouth cleft is not much, if any, above the horizontal line. The pectorals are like those of the Ceratiids, but the dorsal and anal are much

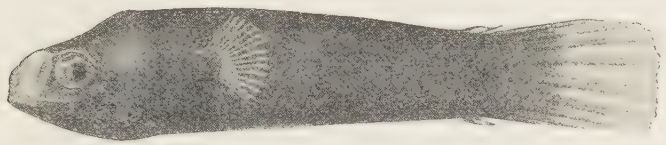
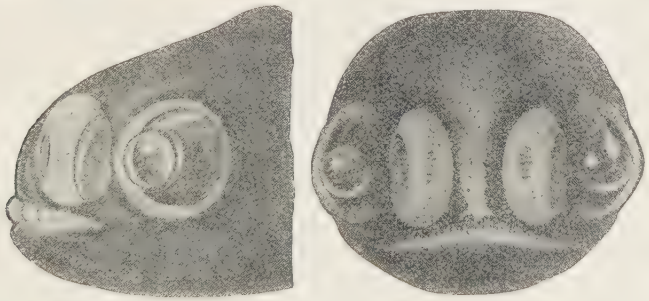


FIG. 26.—Type of the family Aceratiids (*Aceratias macrorhinus*). After Brauer.

reduced in size and far back; the ventrals absent. The illicium is entirely suppressed, but the interspinal bone appears to be developed, though mostly concealed beneath the skin.[a] Instead of the lantern-like or phosphorescent bulb of the illicium manifest in the Ceratiids, the nasal capsules of the Aceratiids are peculiarly developed and may perhaps exhibit phosphorescent emanations.

No species of this group were known till the present decade and the cruise of the deep-sea expedition of the German steamer *Valdivia*.



FIGS. 27, 28.—Side and front views of the head of *Aceratias indicus*. After Brauer.

On overhauling the fishes of the expedition specimens were found by Dr. A. Brauer, noticed in 1902, and later (1908) referred to a "new family."

Three forms of the family have been described by Doctor Brauer, all obtained from depths of 1,000 fathoms or more—one in the Atlantic Ocean and two in the Indian Ocean. All the specimens were young, being less than an inch long.

[a] Doctor Brauer has not described an interspinal bone, but his figure (Pl. XVI, figs. 8 and 9) seem to represent one; so, at least, I am tempted to interpret the illustrations.

THE OGCOCEPHALIDS OR MALTHIDS.

The family Ogcocephalids, or bat fishes, is in some respects, at least, the most distinctly differentiated family of the Pediculates. The head is large and much depressed, and, in most of the species, presents considerable superficial appearance to that of the anglers, but the branchial apertures are in or behind the upper (and not lower) axils of the pectorals; those fins are strongly geniculated, and the elongated pseudobrachia have each three actinosts; ventral fins are well developed and jugular; the first dorsal is obsolete or represented by a single "rostral tentacle" which may be deflected downward by the horizontal extension of the forehead; the soft dorsal and anal fins are very short and few-rayed (D. 4–7, A. 3–4), and in one genus (*Halicmetus*) the dorsal is entirely suppressed.

The most remarkable feature of the osteology is the great development of the opercular apparatus, which is correlated with the superior position of the branchial apertures; the operculum and subopercular plate expanding and prolonged backward and downward.

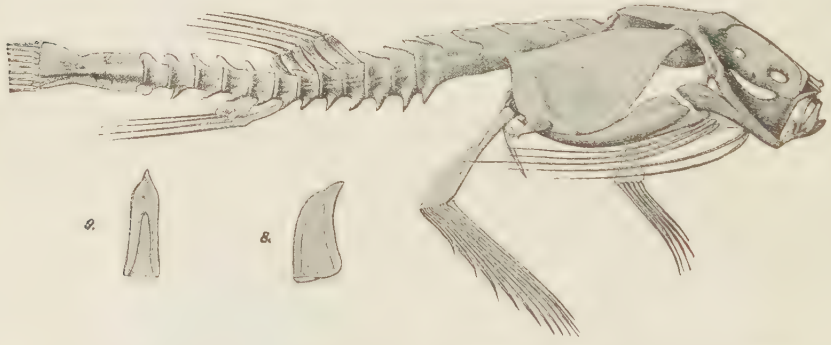


FIG. 29.—Skeleton of a Malthid (*Malthopsis spinulosa*). After Garman.

For a long time the only genera of the family known were *Ogcocephalus* or *Malthe* from the American coast and *Halieutæa* from the China-Japanese waters. Later explorations, however, have brought to light over thirty species representing as many as twelve genera. Only three species of *Ogcocephalus* and one of *Halieutæa* are inhabitants of shoal waters, all the others being deep-sea fishes, occuring mostly at depths between 100 and 500 fathoms.

The family has been disintegrated into two subfamilies, Ogcocephalines, or Maltheines, and Halieutæines, but they run into each other.

The typical Ogcocephalines are distinguished from all other fishes by a unique character. The forehead is produced into a nearly horizontal process which is so extended as to deflect the rostral tentacle (a vestige of the first dorsal fin) so that it is actually directed down-

ward. This is well illustrated by a front view of the fish. The tentacle is retractile into a pit under the fronto-rostral process or horn.

The singular elongation and geniculation of the so-called arms (pseudobrachia) and pectorals and the position and character of the ventrals enable the fishes to progress, as quadrupeds do, by hopping; at least so it has been claimed. Swainson (1838) published an illustration of a *Malthe*, purporting to be "accurately drawn from a specimen [he had] secured on the Brazilian coasts," in such an attitude. The relative functions of the members are curiously reversed, for the homologues of the fore limbs are in these fishes hind limbs and saltatory, while the homologues of the hind limbs are advanced to an anterior position. The present writer has had no opportunity of late years to observe living fishes. Indeed, although not rare, almost nothing is known of their habits.

The most common of the species is *Ogcocephalus* or *Malthe vespertilio*. Sea bat and Toadfish, or simply toad, are vernacular equivalents. Mr. Barton A. Bean has kindly communicated to me some observations respecting its occurrence and habits:

FIG. 30.—A Malthid at attention. After Swainson.

In regard to the occurrence and movements of *Malthe* I can only say that these fishes are common around the docks, in shallow water, of Key West Harbor, Florida. In 1901 (January and the first week of February) I spent three weeks in Key West preserving fishes in formalin for exhibit at the Pan-American Exposition held at Buffalo, New York. My outfit for the work was kept in a small shed at the end of a pier around which, at low-water stage of tide, the sea was shallow; the water was clear and the bottom plainly seen. "Toads" were common (the people at Key West always called them "just toads") and were often observed resting on the bottom or swimming through the water, rather rapidly I thought for so sluggish-looking fish. Owing to the similarity of their color to that of the bottom of the harbor, they were not easy to see at times, and when frightened, in their hurry to move away, they would stir up the water and bottom so that it was impossible to see them again until they passed into clear water and had come to rest some distance off. The fish would rest on its pectorals, but I do not recall seeing one move as if walking; neither could I tell how much the pectorals were used in swimming.

The distribution of *Malthe* would make an interesting study. On the Orian we found them between the Florida Keys, 60 miles or so southwest of Miami (in December), and from that southward you find them more or less common according to bottom. Among the keys north of Key West we seined them in water with hard bottom, but on which there is considerable sediment, broken coral, "rotten sponges," rocks, etc. Around Key West Harbor the fish, as I have already stated, was fairly common. Elsewhere it was not so well known. On our last fall trip I was introduced to a fisherman at New Smyrna, Florida,

who told me that he had quite a curiosity to show me; from his description I told the man that his fish was a *Malthe* and, on showing him a picture of the animal, he said that was it. Later he went home and procured the specimen

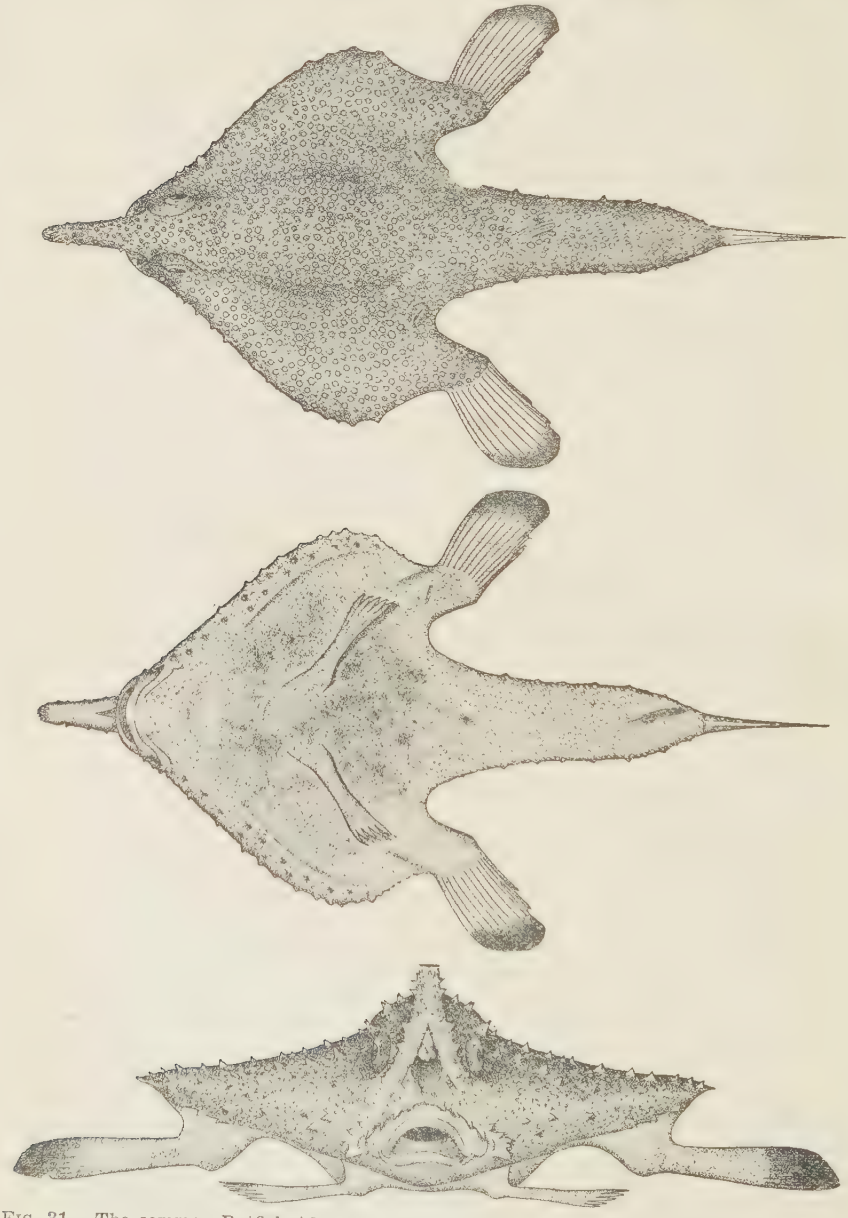


FIG. 31.—The common Batfish (*Ogcocephalus vespertilio*). Views from above, below, and from the front. After Jordan and Evermann.

for me, taking it from a trash barrel into which he had thrown it. He said it was the second specimen he had seen, and he is a man of considerable experience. Our captain (Pine), whose home is in New Smyrna, told me afterward that the fish is occasionally taken there, but is rare.

In 1903 in our explorations in the Bahama Islands we did not secure a specimen of *Malthe*. I saw some dried in the curio shops, but not knowing where they came from did not collect any.

The number of species of *Ogcocephalus* is not quite certain. Jordan and Evermann, however, recognize three species for the eastern coast of America, and Garman has described a species which he considers to be "intermediate" between the *O. vespertilio* and *O. longirostris* from off the Cocos Islands (lat. 5° 32′ 45″ N., long. 86° 54′ 30″ W.). The Pacific Ocean species was obtained from a depth of 66 fathoms.

Another species of the Ogcocephaline group is also an inhabitant of the Pacific waters and has been dredged off the coasts of Mexico and Central America; it has a broader disk than the typical *Ogcocephali* and has been named by Jordan and Evermann *Zalieutes elater*.

FIG. 32.—*Malthopsis luteus*. After Alcock.

The Halieutæines have the forehead flat, or nearly so, the disk generally rounded or truncate in front and the rostal tentacle (when present) directed forward. The species are of small size, ranging mostly from little more than an inch, as in the case of *Halieutella lappa*, to about 6 inches, to which size *Dibranchus atlanticus* sometimes attains. It must be remembered, however, that in most cases our idea of the size is obtained from knowledge of few individuals, and may require to be modified hereafter. Another noteworthy fact is that a reddish color or hue is dominant in most of the species, but not in all. This color is largely associated with fishes of the moderately deep but not abyssal seas.

With the exception of the Chinese and Japanese *Halieutæa stellata* all the species are inhabitants of deep seas. They are distributed among nine genera, distinguished by the presence or absence of vomerine and palatine teeth, the number of gills (whether 2 or 2½ pairs), the size and direction of the mouth, and the form of the disk.

There is a genus which has been named *Malthopsis* and approximated to *Malthe* (*Ogcocephalus*), which, however, is rather more related to *Halieutæa* and its kindred, so far at least as most of the species associated with it are concerned. The typical species (*Malthopsis luteus*) is exceptional on account of the projection above the

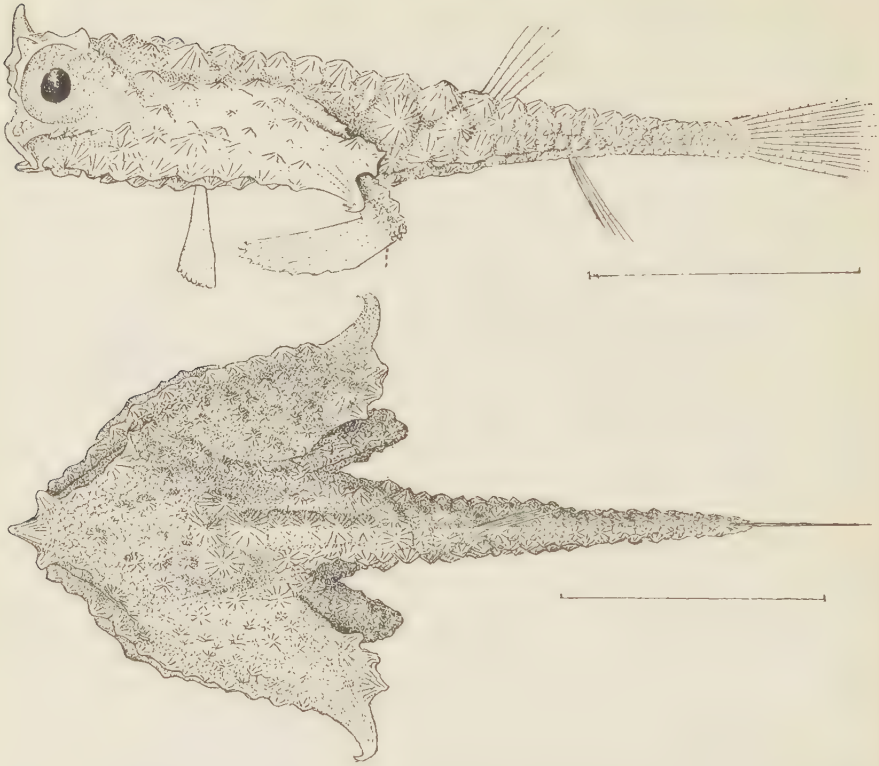


FIG. 33.—*Malthopsis mitriger.* Views from side and from above. After Gilbert and Cramer.

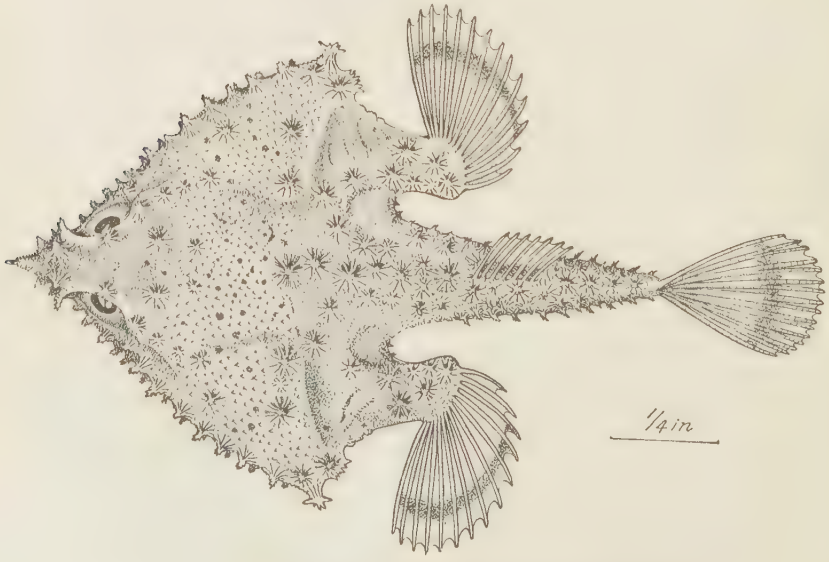


FIG. 34.—*Malthopsis tiarella.* After Jordan and Sindo.

rostral region and may render necessary the reunion of the Ogcocephalines and Halieutines. *Malthopsis* is a genus of eight or nine species having in common teeth on both the palatine and vomerine bones,

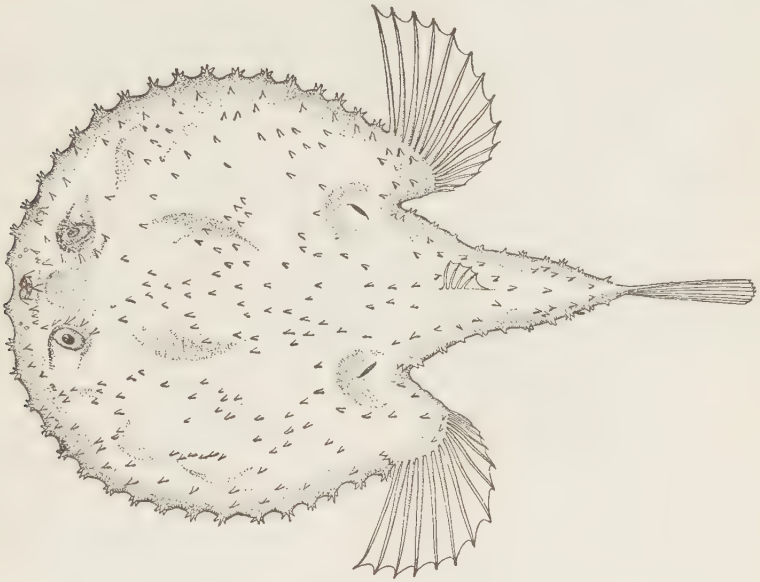


FIG. 35.—*Halieutæa stellata.* After Temminck and Schlegel.

branchiæ only on the second and third arches, and a dorsal fin with five or six rays. Other examples of the genus are the *Malthopsis mitriger* and *Malthopsis tiarella.*

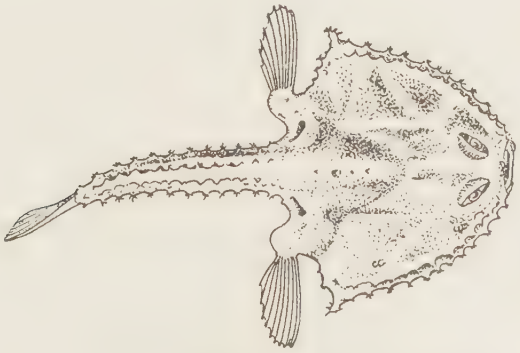


FIG. 36.—*Halieutæa coccinea.* After Alcock.

The longest known of the Halieutine genera is *Halieutæa* typified by the *Halieutæa stellata* of the Chino-Japanese waters. But little is known of its habits, and by Jordan and Sindo (1902) it was de-

clared to be, along the "coast of Japan, not very common," but nevertheless dried specimens, 2 or 3 inches long, may be occasionally found in the boxes of shells and other animal curiosities exported by Chinese. A distinctive name has been given by Japanese fishermen—Akogutsu, meaning "red shoe." The genus is distinguished by the combination of a toothless palate and the development of a half-gill on the fourth branchial arch (2, ½). Other species of the genus are the *Halieutæa coccinea*, *H. nigra*, *and H. gardineri* of the Indian Ocean, found at depths of 123 to 265 fathoms.

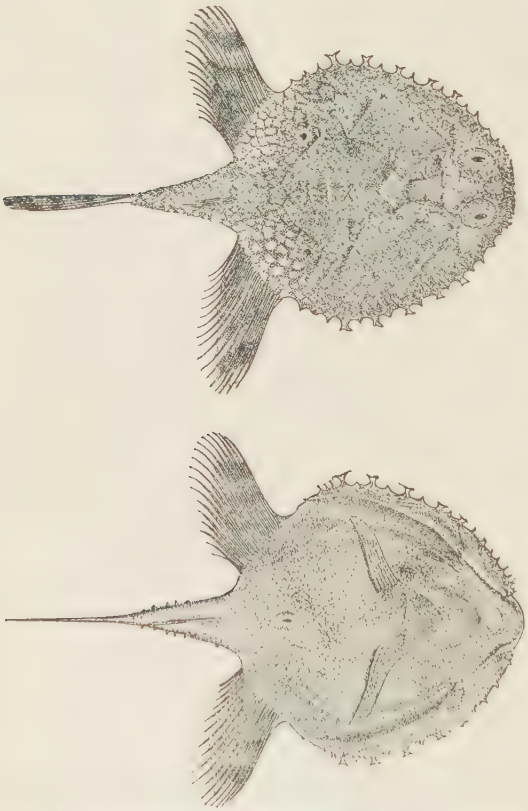


FIG. 87. *Halieutichthys aculeatus*. Views from above and below. After Goode and Bean.

The Halieutine, next to the *Halieutæa stellata* longest known, is the *Halieutichthys aculeatus*, first imperfectly described as a *Lophius* in 1818 by Mitchill, but not adequately made known till 1863. It is also one of the most common and least bathyphilous species of its group. It has been or may be found in almost any place with a fitting bottom in the Gulf of Mexico or Caribbean Sea or along the coast of Florida at any depth from 9 to 95 fathoms. The color is more varied than in most of the Halieutines. According to Goode and Bean, the body is "covered above with reticulations of brown, the general hue varying from light yellowish gray to grayish brown, the markings being darker upon darker specimens; pectoral and caudal fins with about three dark bars; the terminal bars in young very black; body beneath, milky white." The palatines as well as the vomer are provided with teeth; the gills are reduced to the perfect ones of the second and third branchial arches. The disk is subcircular or ovate.

Almost all of the Halieutines are much depressed, but an exception is manifest in the *Halieutella lappa*, as will be evident from the two figures here reproduced. The body is unusually convex above as well as below, and the two surfaces are limited by the zone of spiny tubercles which beset the sides of the disk as in other species of the family. The subglobular shape, as well as spinescense, have suggested the name *lappa* (burdock) which has been given to it. The only specimen yet found was a small one (1¼ inches long) dredged from a depth of 125 fathoms off the New England coast (lat. 39° 58′ 30″ N., long. 70° 37′ W.). Two other species, however, have been described. Except for form the species agree with Halieutichthys and, like that genus, have vomerine and palatine teeth as well as a half-gill on the fourth arch (2, ½).

Fig. 38.—*Halieutella lappa*. Views from side and above. After Goode and Bean.

So far as our present knowledge goes, the most abundant and generally distributed of the Halieutines is the *Dibranchus atlanticus*, first made known in 1875, very numerous specimens having been dredged in the Atlantic Ocean and near the African as well as American coast at depths ranging between 22 and 523 fathoms. A single specimen was obtained off Block Island in 1880. The color is "uniform reddish gray above, slightly lighter below." The disk is ovate and modified in appearance by the development of opercular spines or processes behind the lateral borders. The generic characters are absence of teeth from the roof of the mouth, absence of gills from the first and fourth gill-arches, and the slightly produced supra-rostral region.

Half a dozen species of *Dibranchus* have been described in recent years from the Pacific and Indian oceans, as well as the Atlantic.

A third subfamily type (Cœlophrynines) is represented by a small Ogcocephalid described by Dr. A. Brauer in 1902. In this the body

and pectoral members are not extended laterally as in the preceding, but the form is oblong, the head truncate forward and with a very spacious rostral cavity provided with a wide and complicated tenta-

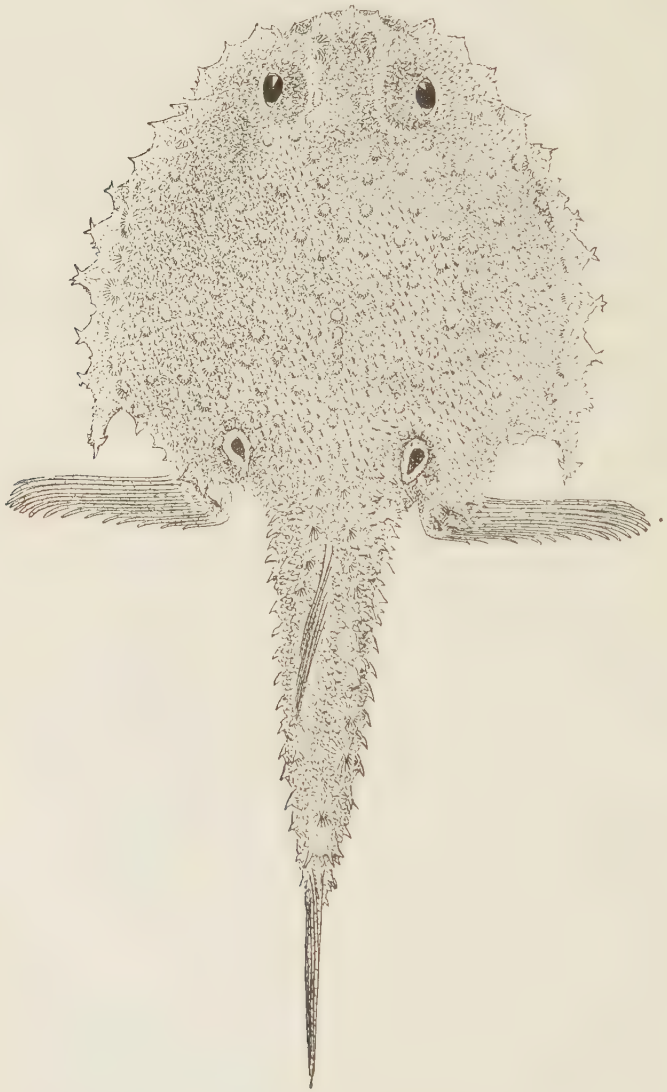


FIG. 39.—*Dibranchus atlanticus*. After Goode and Bean.

cle, and the pectoral members are less free and divergent from the body than in other Ogcocephalids. Another remarkable characteristic is the very backward position of the branchial apertures within the axillæ of the pectoral members, so that they are much nearer to

the caudal fin than to the ridges of the head. The only species known is the *Cœlophrys brevicaudata*, of which a single specimen was

FIG. 40.—A peculiar Maltheid found off Sumatra at a depth of 1,024 meters (*Cœlophrys brevicaudata*. Views from above (*a*) and from the side (*b*). After Brauer.

obtained in the Indian Ocean from a depth of about 500 fathoms (1,024 meters).

PART II.

THE HABITS OF TYPICAL ANTENNARIIDS.

Very little is known of the habits of most of the Pediculates, but considerable has been ascertained of the peculiar characteristics of species of the best-known genera of the family of Antennariids. This has been collected here from many sources.

ANTENNARIUS.

The genus *Antennarius* has the body covered with prickles or minute spinules, the mouth is subvertical, the caudal peduncle free, the wrists and pectoral fins wide, the pectorals entire, the ventrals short, the dorsal fin (12) moderate and less than half as long as the body, the third dorsal spine more or less concealed below the skin, and the anal oblong and provided with seven or eight rays.

Such are the characters which serve to distinguish the genus from *Pterophryne* as well as *Rhycherus*, *Histiophryne*, *Saccarius*, and *Tathicarpus;* other genera of the same subfamily are so far removed

by their characters as not to demand special consideration here. The species may be designated as "sea toads."

The fishes here called "sea toads" are generally known to the inhabitants of most British tropical colonies as "toad fishes," but in Jamaica and some other West Indian islands sea toad is used, and that quite apt name may be adopted and contrasted with frog fish, a name sometimes applied to the sargasso fish. There is a further aptness from the fact that the sea toads contrast with the frog fishes in a manner analogous to that manifest in the real toads and frogs, the former having very rough skins and the latter smooth ones. As every coast-frequenting American knows, toadfish is applied by fishermen to a very different fish—the *Opsanus* of naturalists.

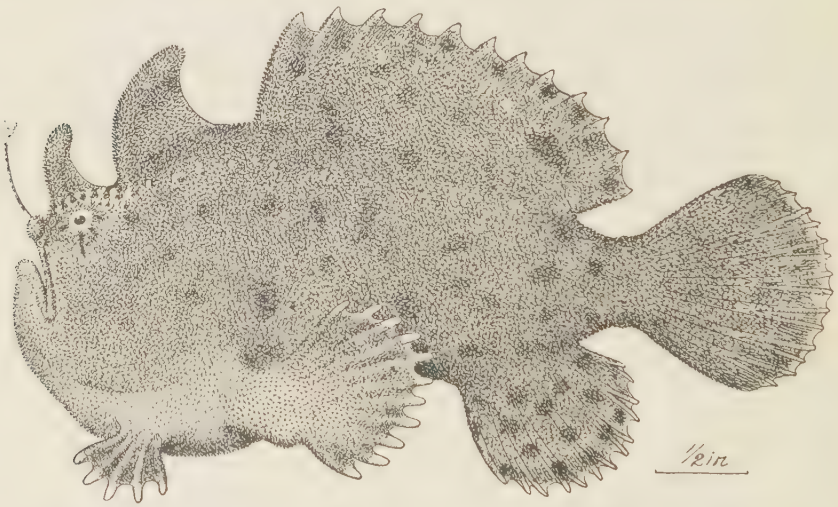


FIG. 41.—A typical Antennarius (*Antennarius nox*). After Jordan and Snyder.

The sea toads are inhabitants of tropical seas, and especially of the coralligenous zone, and in the environments characteristic of such waters they find fitting homes, where accommodation and food are alike secured. As the frog fishes, or sargasso fishes, are adapted by their coloration to the peculiar conditions under which they live, so are the sea toads to their different circumstances. The brilliant scarlet and other colors, which render them so conspicuous when seen in the jars of a museum collection, are quite in harmony in their natural home and assimilate the fishes to the brilliantly colored coral animals and the other organisms in the midst of which they lurk in wait for prey. Their habits and behavior are best known through observations made by the Rev. S. J. Whitmee in 1875, of captive individuals of the *Antennarius coccineus* and *Antennarius multiocellatus*.

The species are ill fitted for progression and most of their lives are spent in coral growths where they may find lodgment, and which

may be visited by animals, some of which are liable to be attracted by the expectation of a tit-bit, or by curiosity, sufficiently near to be engulfed for food. Selecting a fitting place, such as a fissure or intervale between neighboring masses, just wide enough to get into and hold on to, a fish may assume an oblique or vertical position, sometimes looking downward, sometimes with head upward; it then uses its pectoral fins to obtain a good purchase on the rock—a foothold or rather a finhold—and can thus remain stationary indefinitely.

A living fish, the *La'otali* of the Samoans (*Antennarius coccineus*), was carried to Whitmee and consigned to an aquarium.

It was brought in a cocoanut shell with very little water, and its stomach was greatly distended with air. When put into the aquarium it was some minutes before it could sink. It struggled hard to get down, and as the air was discharged it went down and immediately attached itself, in a vertical position, to a block of coral by means of its pectoral and ventral fins. These were distended, and looked very much as if they served the purpose of sucking disks (like the united ventrals of the *Gobidæ*) as well as answering in place of feet.

When attached it held on firmly and was with difficulty disengaged. Natives assured Whitmee that they had "taken up a block of coral with this fish attached," and had "great difficulty in shaking it off."

An example of another species, the *Antennarius multiocellatus*, in the main behaved like the *La'otali*, but assumed a different attitude. It was taken to Whitmee out of the water and had been out several minutes.

It seemed somewhat exhausted, but soon recovered when placed in the water. It affected a singular position. It moved occasionally from one place to another, and evidently preferred a position between two coral blocks near together. Here it planted its ventrals firmly on the sand at the bottom of the aquarium, while it fixed its pectorals in the manner of disks, on the sides of the blocks of coral between which it was stationed, and raised its posterior extremity at an angle not far from the vertical.

In this position it reminded Whitmee

of the antics of "city Arabs" who walk on their hands with their legs in the air; its posture was almost exactly that assumed in such an exercise. The caudal fin was bent over toward the dorsal and in a line with it, while the anal was brought almost into line with the major axis of the body, occupying the position belonging to the caudal. Whenever it fixed itself for any length of time, it was always in this position, and in that attitude it angled with the ciliated anterior dorsal for some of the small fish in the aquarium.

When the sea toads attempt to swim, in the familiar words of Whitmee, they "cut a poor figure." The *Antennarius coccineus* "prepared to walk where it could," but only enough to go a short distance from one position to another.

Although highly carnivorous, as their oral structure indicates, they are not active hunters, but wait till their victims come sufficiently near to be seized. Their presence is disguised by accommodation to

their surroundings. The *La'otali*, "after a few minutes," moved "from the first position and, apparently, sought one better adapted to its habits." It then

fixed itself, in a vertical position with the head up, in an indentation in a coral block which pretty well matched its size. When attached it looked much like the block itself, the cutaneous tentacles and ocellated spots greatly resembling the fine seaweed and colored nullipores with which the dead portions of corals and stones are more or less coated in tropical seas.

It indeed appeared to Whitmee to present a case of mimicry and accommodation to its environments.

Being a slow swimmer and carnivorous it has to get its food by stratagem. Hence the advantage of those characteristics which make it so grotesque in appearance—wide vertical mouth, rough and spotted skin, with cutaneous tentacles, and the anterior dorsal spine modified into a soft tentacle.

They catch fishes if they can, and eat them when they can get them. The *La'otali*, soon after being transferred to the aquarium

vomited a slightly decomposed fish 1 inch 5 lines in length. This was one of the small fishes always seen in great abundance about the coral patches, nibbling at the fine seaweeds and the growing points of the corals. The capture of such fishes when unconsciously approaching it,

Whitmee thought, would be

greatly facilitated by the strong current produced when this *Antennarius* sucks the water into its capacious jaws. From its vertical position, when fixed on a stone, the jaws open horizontally, and they are very wide.

When examining the fish Whitmee placed it in a basin with about a pint of water. So much water was drawn into the jaws and expelled with such force through the branchial "foramina, which are directed backward behind the pectorals, that a rapid rotatory motion was produced in all the water. This," it was thought, "would be sufficient to engulf many a small fish or crustacean within its stomach." Whitmee was unable to observe his fishes feeding.

The geniculate pectorals and the attitude the sea toad assumes suggest the possibility, if not probability, that it may use its coral foothold as a base from which to leap upon a fish attracted near enough to justify the attempt. Doubtless the general belief that some fishes are attracted by the appearance of the "bait" or appendages of the cephalic spine has a foundation in fact, and an incautious fish may come so near that the angler can spring upon and capture it before the victim finds out its mistake.

Nothing is known of the reproductive processes of any species of sea toad. Since, however, the divergents to such extremes as the angler and the sargasso fish essentially agree in the manner of oviposition, it may be safely assumed that the Antennarii share in the habits and methods derived from a common ancestry. The female sea toads, therefore, doubtless discharge their mature eggs of one ovary

at least all at once and in a jellylike envelope or raft, whose buoyancy floats it at the surface of the water; there the fertilized eggs are developed, and the liberated young at first live near the top, but in due time descend to the coral groves and lead the lives of their parents.

The statement made by Günther that Antennarii are "carried by currents to the coast of Norway and New Zealand, or the northern United States," has not been verified for any true species of *Antennarius*, and is true only of the species of *Pterophryne*. The further assertion that "the extraordinary range of some of the species, which inhabit the Atlantic as well as the Indo-Pacific Ocean, is the consequence of their habit of attaching themselves to floating objects" is also only applicable to the Pterophrynes.

The sea toads are not entirely harmless, if we may trust to the observations of Whitmee. According to him, the natives of Samoa "frequently get stung by the third dorsal spine of this fish when they happen to pick up a block to which it is attached before they are aware of its presence. It causes very great agony, which usually lasts hours, and sometimes two or three days." It is possible or even probable, however, that the really guilty fish is another uncouth animal, somewhat like a sea toad and living in similar positions, but really quite different and known to naturalists as a *Synanceia*. The spines of sea toads are not well adapted for inflicting harmful wounds.

PTEROPHRYNE.

The genus *Pterophryne* has the body naked or granular and merely provided with cutaneous tags or appendages, the mouth oblique, the caudal peduncle free, the wrists and pectorals comparatively slender, the ventrals elongated, the dorsal fin longish (12) and more than half as long as body, the third dorsal spine mostly free and the anal extended downward and with seven rays.

"Frog fish," "mouse fish," and "sargasso fish" are the principal popular names which have been given to fishes of this genus; the first is the one best adapted for use here. As to the scientific name, the *Pterophryne histrio*, it has been claimed, "derives its epithet from the prompt and rapid movements which it gives to its fins and filaments, and which have been compared to scenic gesticulation. Probably it may have been also thus named because it can rapidly swell out its abdomen, and changes its figure, as it were, at will." Such is the explanation given in volume 10 (p. 370) of "The Animal Kingdom," of Cuvier, edited by E. Griffith. It is only necessary to add that Linnæus did not know the living fish and simply gave the name because the varied coloring reminded him of a clown or harlequin.

The frog fishes in the Atlantic Ocean, at least, are mostly inhabitants of the "Sargasso seas," or "Sargasso meadows," in mid-ocean, and in the midst of the seaweed they find congenial homes. The common form of the Atlantic, indeed, is generally called the "sargasso fish" and is, according to J. Matthew Jones (1879), that "one species of fish which, above all others, seems to belong to the *Sargassum*," and "which from its peculiar armlike pectorals is especially fitted to rest upon the weed." Alexander Agassiz also (1888) declared that it was "specially adapted to live among the floating algæ."

It is, as A. Agassiz has suggested and Mosely affirmed, like other inhabitants of the Sargasso Sea, "in the same way colored weed-color

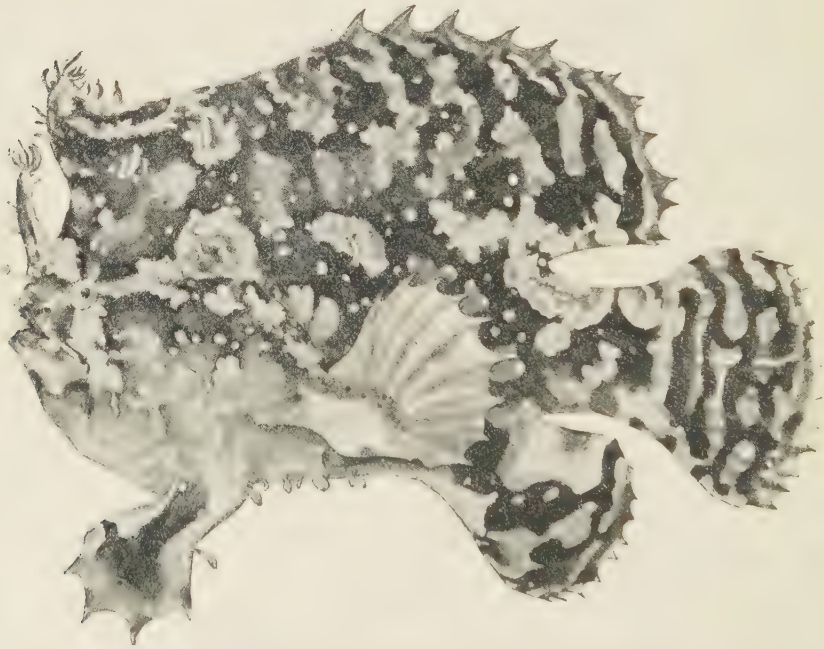


FIG. 42.—A typical Pterophryne (*Pterophyrne ranina*). After Jordan and Snyder.

with white spots," and simulates the appearance of its environments. Still further, there is that same subtle and even marvelous power or rather susceptibility that is evinced by some other animals, of assimilation to the varying hues of the plants amidst which it lurks. This capacity of the fish for assimilation in color to its environments was manifest in individuals observed by Dr. Hugh Smith. The animal, in the midst of living vegetation, exhibits color harmonizing with it, but when the seaweed has decayed to a brownish hue, its color also changes to a corresponding shade. Conspicuous as the fish is when isolated in the water, it has to be searched for when amidst its proper environments.

J. E. Ives (1889) has extended the theory of adaptation to an extreme. According to him

> The ground color of the fish is of a pale yellow, and on this light background are darker irregular brownish bands, closely resembling the branched fronds of the sargasso weed. Along the edges of these darker bands, on the bands themselves, and also to a lesser extent upon the rest of the body, are little white specks of various sizes, on an average about that of a pin's head, and on the dorsal spines, are numerous leaflike cutaneous filaments.

Mr. Ives, "after careful consideration, had come to the conclusion that the color markings of the fish, and the cutaneous filaments, had been developed in mimicry of the Spirorbis-covered sargassum weed."

The sargassum, be it remarked, is one of the fucaceous algæ or seaweeds and is also known as "sargazo" or "sargasso," "gulf weed," "sea lentil," "sea grape." *Sargassum bacciferum* is the specific name mostly given to the kind in question. According to Harvey, "the floating fronds generally grow from a central point, from which branches extend in all directions. In such specimens the base appears to be a fragment of broken branch, rather than a true disciform root." Air vessels are very numerous and "about as big as peas." These "air vessels" or "bladders" buoy up the sargassum on the surface of the sea. The plant increases indefinitely by "the continual breaking up of the old fronds and the continued growth of their broken parts," and "the floating masses spread over the surface of the seas. In this floating state the species never forms proper fructification" and "there is, therefore, no growth from spores."

Although floating on the high seas and thus at the mercy of the winds and waves, nevertheless, those agents operate in such a manner, in conjunction with the currents, that, for year after year and century after century, nearly the same areas of the ocean are covered by the plant. It is, Harvey justly remarks, "curious that the great bank which extends between the twentieth and forty-fifth [?] parallels of north latitude, and in 40° W. from Greenwich, appears to occupy the same position at the present time as it did in the days of Columbus," who first described it. Persistent as it is, a considerable fauna has been developed characteristic of the sargassum or sargasso meadows.

The animals that find homes in such quarters represent most of the classes of which species are found along the shores of continents and islands, such as crustaceans, gastropods, cephalopods, and fishes, and all these may be relied upon for food if they approach within reach of the Pterophryne. Some of the most characteristic of these are swimming crabs (Portunids) of the genus *Neptunus* and the squarish grapsid named *Planes minutus;* small cuttle fishes of the genus *Onychia*, and fishes of the pipefish family (*Siphostoma*) and amber fish (*Seriola*). Flying fishes of different kinds are also tenants of those fields, although they may rarely show themselves in the air.

FIG. 43.—The Sargasso weed (*Sargassum bacciferum*). After Harvey.

Although the ocean area covered by the sargassum is approximately the same for unlimited time, there is, nevertheless, an ever-present liability for drift of individual plants along its borders in directions determined by currents and winds. Naturally the attachés of the plants are drifted with them. Thus it happens that there are not infrequent incursions of the Pterophryne on the American coast and especially along that of Rhode Island and southern Massachusetts. Dr. Hugh Smith

in 1897 had an opportunity to collect many specimens of the fish in Vineyard Sound off Woods Hole and to observe the behavior of numbers kept for several weeks in the aquarium of the Bureau of Fisheries. The species occurs only as an involuntary straggler in that region, and in thirty-five years has been observed there during only five or six seasons. The prevalence of southerly winds and the presence of masses of sargassum are essential to the appearance of the fish on our north Atlantic coast, but even this combination often fails to yield the species. The year in which there was the most noteworthy occurrence at Woods Hole offshore winds prevailed in summer to an unusual degree, and in July large quantities of sargassum were blown inshore from the Gulf Stream, and with it the fish. During the forenoon of July 24, in company with Mr. Vinal N. Edwards,

Doctor Smith secured 22 specimens in the Vineyard Sound

by simply dipping up the pieces of sargassum with a small net, the fish themselves not being visible in the water; on the same day 28 specimens were collected by other persons, and during the remainder of the summer about 50 more were obtained. The fishes transferred to the aquarium were from the outset quite indifferent to captivity and maintained an attitude of repose that was seldom broken.

Under ordinary conditions the Pterophryne is a solitary being, and there is no association in large or even small numbers. It is, in fact, a quarrelsome fish, and as a rule different individuals will not tolerate near approach of their fellows. If several are brought together in a small aquarium, one may not only take advantage of its larger size by nipping off the cutaneous tags of a smaller associate, but end by eating it. Two confined in the Beaufort aquarium were observed by Gudger to be

continually fighting. In these daily combats the smaller suffered considerably, its filamentous appendages and even the ends of its fins being bitten off.

When the smaller fish was at last removed the survivor "did not seem to miss its companion." Several, placed in a larger aquarium at Woods Hole,

occupied different parts of the aquarium—sometimes concealed among algæ on the bottom, sometimes hidden behind stones and other objects, sometimes lying in rocky crevices, and sometimes suspended in or immediately beneath masses of floating sargassum and most effectively concealed by their color and shape.

If one, perchance, approached near another, resentment was shown at the intrusion and, if large enough, the fish trespassed upon would drive away the intruder.

In a state of nature the Pterophrynes are undoubtedly less liable to come into conflict with their fellows and each one has its special lurking place. Most of the Pterophryne's life is spent in quiescence or a state of rest. Those in the aquarium at Woods Hole "maintained an attitude of repose that was seldom broken." One generally attaches itself to a sargassum frond and often actually holds on with downbent and armlike pectoral members at various angles. The most notable of these attitudes is a horizontal position over a sargassum frond with the pectoral limbs stretched downward like a regular arm bent backward, the long wrist simulating the arm and the fin the forearm, while the elbow is mimicked by the joint between the wrist and fin; the fin acts as a hand applied to the sargassum.

The Pterophryne, like all of its relatives, is a highly carnivorous fish, and it is not fastidious in its appetite. Doubtless almost any of the inhabitants of the meadow of suitable size is a welcome incomer. A single Pterophryne, whose stomach contents were examined by Möbius (1894), was found to have taken in four fishes, one of which, a pipe fish (*Syngnathus* or *Siphostoma pelagicum*) over 5 inches (135 mm.) long, was coiled in the stomach, a small cuttle fish (*Onychia curta*), and a small portunid crab (*Neptunus*); all these were still in a recognizable condition. This may give a faint idea of the range of food supply. Those confined in the aquarium at Woods Hole were given minnows, and fed upon such entirely unfamiliar fishes with the same avidity as upon those they had been accustomed to in their native waters.

If careless or unlucky animals approach too near a Pterophryne, the quiescent but hungry fish is stirred instantaneously into vigorous action. It leaps upon its prey as quickly as a tiger would upon its own. But it by no means always awaits for the approach of a victim. According to Smith, one may "stealthily approach and when sufficiently close to an animal, literally pounce upon it." Another was observed by Gudger to draw near a destined victim, "first with closed mouth," and at last, when within striking distance, suddenly protrude its jaws and, with open mouth, "take in its prey with an instantaneous gulp." Sometimes, however, the desired prey becomes alarmed and dodges just in time and swims away; the Pterophryne, his appetite now whetted, swims after and, notwithstanding his apparent sluggishness, frequently overtakes and captures the fleeing fish.[a]

Unlike the common angler, the Pterophryne readily accommodates itself to life in an aquarium without loss of appetite. The aquarium

[a] The hunting down of the small fishes was observed by Professor Gudger, who has informed me that the Pterophryne, in the globe in which it was confined, was almost sure to capture the victim in a very few rounds in the aquarium. Whether it is equally persistent in the open sea may be doubted.

of the laboratory of the United States Bureau of Fisheries at Beaufort had a couple which were observed by Gudger to feed "voraciously, eating pieces of oyster, bits of shrimp, and small fishes, alive or dead." Others thrived in aquaria at Woods Hole, and were noticed by Hugh Smith. The several individuals

were clumsy in their movements, and often made prodigious efforts to go short distances. At the same time, they approached their prey stealthily, and literally pounced upon it. Their wide mouth enables them to capture and swallow fishes that are entirely disproportionate to their own size.

This was well illustrated by the habit of eating their fellows, of which Smith observed several cases.

On one occasion a specimen 6 inches long captured and swallowed intact another nearly 4 inches long, and did not seem particularly incommoded thereby. They persistently bit off the dermal flaps of their fellows, so that after a few days nearly all of them were more or less completely stripped of these appendages. This habit was exhibited when there was an abundance of minnows on which to feed. Cannibalism in this species has been noted by other observers.

The spawning time of the sargasso fish may extend over a considerable period. Its newly matured eggs have been observed from mid and late summer (July and August) to late in the fall (October). Evidence of the maturation of the eggs becomes manifest by swelling of the abdomen and, according to Gudger, sometimes "in front of the arms, becoming as square as if it had been cut to shape with a knife." Soon after this condition has been attained the eggs are discharged in a jellylike mass, which becomes swollen on contact with the water and enlarged into a narrow raft, 3 or 4 feet long, although the mother fish may have been "only 3 or 3½ inches long," and "had only about one-third of the volume of the eggs and jelly combined."

The act of spawning had not been described till Dr. Hugh Smith observed it at Woods Hole. There, in 1897, "several spawned in the aquarium in August, but the eggs were not fertilized. The eggs were buoyant and combined in long bands or strings like those of the goose fish (*Lophius*)." At the Beaufort laboratory, in 1894, a sargasso fish, which had been seven weeks in captivity, laid a long string of eggs on July 25. In every subsequent year oviposition was repeatedly observed.

The prolonged time during which spawning may occur appears to be partly due to the difference in the development and maturation of the two ovaries. In the case of a female, especially observed in 1906, Doctor Smith found that there was one issue of eggs in a raftlike mass on the 6th of September and a second on the 10th of October, and in 1905 another female matured one raft of eggs in August and later one in September. Nevertheless, occasionally, according to an

FIG. 44.—Raft with eggs of a Pterophryne. Reduced after a photograph from Dr. Hugh Smith.

observation of Dr. Ulric Dahlgren, an individual may exclude two egg rafts at the same time.

The egg raft, after full expansion in the water, is a soft jellylike mass, quivering to the touch, but withal rather tenacious and 3 or 4 feet long by 2 to 4 inches or thereabouts in breadth, moderately uniform in the width, and tapering abruptly and blunt at the extremities. It is also rather thick, with blunt edges. The entire mass is thickly permeated with eggs, which appear to be in several irregular layers, or at least more than one. After some days, and when the eggs have matured, the jelly probably dissolves and embryos are apparently thus liberated, but exact observation is necessary to confirm (or disprove) this supposition. The eggs are innumerable and each one, when fresh, about a millimeter in diameter, but according to Gudger, "after having been in a formalin solution measured not much more than half (0.60) of a millimeter in diameter."

Also, according to Gudger, "there are no oil drops visible in the living eggs of Pterophryne," but, "in sections, some eggs show a small number of minute vacuoles indiscriminately scattered under the germ disk and around the circumference of the yolk. Some are devoid of these."

All of the many Pterophrynes that have been found in the sargassum drifted on the American coasts have been females, or at least none has been recognized as

a male. Consequently no observations have been made on the relative behavior of the sexes or on the mode of fertilization of the eggs. All this has yet to be observed.

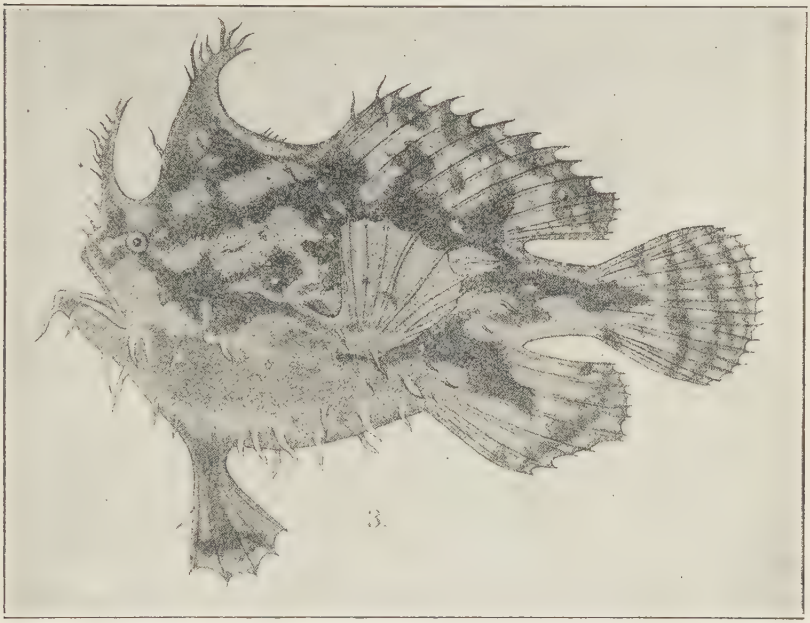


FIG. 45.—The Frogfish or Marbled Angler (*Ptcrophryne histrio*). After Smitt.

The *Pterophryne* naturally would not be generally looked upon as an edible fish and, according to Schlegel, even the piscivorous Japanese consider the flesh of the species to be poisonous. As such it is ranked by Pellegrin in Les Poissons Vénéneux.

PART III.

THE SO-CALLED "NEST" OF THE FROG FISH.

A summary of all that has been positively made known of the habit of the frog fish has now been given, but a remarkable episode in its history deserves to be here recorded. For just about a generation (thirty-three years) that fish was signalized as a nest maker, the fabricator of a subglobular nest constructed from a frond of the sargasso weed, in the midst of which it is most abundant. This supposed function was the result of a misidentification of eggs found in connection with masses of sargassum frequently to be met with in or about the winter months in subtropical waters.

The first to notice the egg masses was Prof. Louis Agassiz, who obtained one during a voyage in the coast survey vessel *Hassler* near the

island of St. Thomas, West Indies, in December, 1871. He gave a very interesting account of the supposed nest in a letter to the superintendent of the United States Coast Survey, which was published in the American Journal of Science and Arts for February, 1872, (third series, Vol. III, pp. 154–156). The article was republished in whole or part far and wide. He may declare for himself:

The most interesting discovery of the voyage thus far is the finding of a nest built by a fish floating on the broad ocean with its live freight. On the 13th of the month [December], Mr. Mansfield, one of the officers of the *Hassler*, brought me a ball of gulf weed which he had just picked up and which excited my curiosity to the utmost. It was a round mass of sargassum, about the size of two fists, rolled up together. The whole consisted to all appearance of nothing but gulf weed, the branches and leaves of which were, however, evidently knit together and not merely balled into a roundish mass; for, though some of the leaves and branches hung loose from the rest, it became at once visible that the bulk of the ball was held together by threads trending in every direction, among the seaweed, as if a couple of handfuls of branches of sargassum had been rolled up together with elastic threads trending in every direction. Put back into a large bowl of water, it became apparent that this mass of seaweed was a nest, the central part of which was more closely bound up together in the form of a ball, with several loose branches extending in various directions, by which the whole was kept floating.

FIG. 46.—Supposed nest of Pterophryne. After A. Agassiz.

A more careful examination very soon revealed the fact that the elastic threads which held the gulf weed together were beaded at intervals, sometimes two or three beads being close together, or a bunch of them hanging from the same cluster of threads, or they were, more rarely, scattered at a greater distance one from the other. Nowhere was there much regularity observable in the distribution of the beads, and they were found scattered throughout the whole ball of seaweeds pretty uniformly. The beads themselves were about the size of an ordinary pin's head. We had, no doubt, a nest before us, of the most curious kind; full of eggs too; the eggs scattered throughout the mass of the nest and not placed together in a cavity of the whole structure. What animal could have built this singular nest, was the next question. It did not take much time to ascertain the class of the animal kingdom to which it belongs. A common pocket lens at once revealed two large eyes upon the side of the head, and a tail bent over the back of the body, as the embryo uniformly appears in ordinary fishes shortly before the period of hatching. The many

empty egg-cases observed in the nest gave promise of an early opportunity of seeing some embryos freeing themselves from their envelope. Meanwhile a number of these eggs with live embryos were cut out of the nest and placed in separate glass jars to multiply the chances of preserving them, while the nest as a whole was secured in alcohol, as a memorial of our unexpected discovery. The next day I found two embryos in one of my glass jars; they occasionally moved in jerks, and then rested for a long while motionless upon the bottom of the jar. On the third day I had over a dozen of these young fishes in my rack, the oldest of which began to be more active, and promised to afford further opportunities for study.

* * * But what kind of fish was this? About the time of hatching, the fins of this class of animals differ too much from those of the adult, and the general form exhibits too few peculiarities, to afford any clue to this problem. I could only suppose that it would probably prove to be one of the pelagic species of the Atlantic, and of these the most common are *Exocœtus*, *Naucrates*, *Scopelus*, *Chironectes*, *Syngnathus*, *Monacanthus*, *Tetraodon*, and *Diodon*. Was there a way to come nearer to a correct solution of my doubts?

As I had in former years made a somewhat extensive study of the pigment cells of the skin, in a variety of young fishes, I now resorted to this method to identify my embryos. Happily we had on board several pelagic fishes alive, which could afford means of comparison; but unfortunately the steamer was shaking too much and rolling too heavily for microscopic observation of even moderately high powers. Nothing, however, should be left untried; and the very first comparison I made secured the desired result. The pigment cells of a young *Chironectes pictus* proved identical with those of our little embryos.

It thus stands as a well authenticated fact that the common pelagic *Chironectes* of the Atlantic (named *Chironectes pictus* by Cuvier) builds a nest for its eggs in which the progeny is wrapped up with the materials of which the nest itself is composed; and as these materials are living gulf weed, the fish cradle, rocking upon the deep ocean, is carried along as an undying arbor, affording at the same time protection and afterwards food for its living freight.

This marvelous story acquires additional interest if we now take into consideration what are the characteristic peculiarities of the *Chironectes*. As its name indicates, it has fins like hands; that is to say, the pectoral fins are supported by a kind of prolonged, wristlike appendages, and the rays of the ventrals are not unlike rude fingers. With these limbs these fishes have long been known to attach themselves to seaweed, and rather to walk than to swim in their natural element. But now that we have become acquainted with their mode of reproduction, it may fairly be asked if the most important use to which their peculiarly constructed fins are put is not probably in building their nest.

While Agassiz soon reached the conclusion that the nest maker was the Antennariid so common in the seaweed, he did not continue his investigation of the subject,[a] and it was many years before a more searching inquiry into the constitution of the nest was made. Then the subject was taken up by a French naturalist, Leon Vaillant.

A number of the nests were obtained by Vaillant and the supposed procedure of the nest maker was described in 1887.[b] Only a summary

[a] Agassiz died Dec. 14, 1873.

[b] Remarques sur la construction du nid de l'*Antennarius marmoratus* Less. et G., dans la Mer des Sargasses. CR. des séanc. de la Soc. de Biologie, (8) IV, 1887, p. 732–733.

of his account need be given. It was explained that each nest was composed of a single plant or tuft (frond) of the gulf weed (*Sargassum bacciferum*), and by commencing with the slenderest outer branchlets and peeling all successively off, an entire frond could be spread out. A frond, then, of gulf weed, it was assumed, was selected by a *Pterophryne* with ripe eggs and she proceeded to make a receptacle or nest for the eggs. She places herself in the center or starting point of a tuft and connects together the basal branches, placing some eggs and with them a glutinous thread which binds together the next dividing branches, and so on until she brings together the terminal branchlets and forms a spheroidal mass or nest, as large as a couple of fists or perhaps a man's head. All the time she unloads her eggs in the mass and in so doing improvises the thread needed for binding the mass together. Indeed, Vaillant observes, the binding material which this fish uses in her labor, in all probability, is of the same nature as the agglutinative substances which many other fishes employ to fix their eggs and which they secrete at the moment of spawning. They are in the form of filaments of extreme tenuity ("0^{mm}, 010 à 0^{mm}, 015"), very regularly calibrated save at the points of adherence to the eggs, where there is generally found a kind of expansion. These filaments are brought together in greater or less number to form cords of which the diameter may sometimes exceed half a millimeter.

Another long account of "nests" and eggs attributed to the sargasso fish was published by K. Möbius in 1894.[a] The mass was obtained in midocean (4° 45′ N. lat., 30° 40′ W. long.), and was sacciform, 50 centimeters deep and with a diameter of 40 cm.; it had two openings, one 25 cm. wide and another 10 cm. wide. The eggs were distributed through the mass, and it was estimated that the aggregate of 1,130,574 was distributed therein.

The eggs, according to Möbius, had an average diameter of more than a millimeter and a half (1.67 mm.), and at both poles were developed bunches of more or less elongated filamentary processes; in each cluster are from 15 to 30 filaments, 7 to 12 thicker and 12 to 21 thinner. Some of these filaments were as much as half an inch (12 mm.) long; all were very slender, some thicker (16–24 μ) with wider conical bases of insertion (32–64 μ thick), others thinner (8–10 μ) with correspondingly reduced bases (32–40 μ). It is by means of these tendril-like filaments that the eggs are kept in place in the nest.

Möbius has especially insisted that for the eggs thus provided for, the female is responsible and not, as in the case of the Stickleback,

[a] Über Eiernester pelagischer Fische aus dem mittelatlantischen Ocean. SB. K. Preuss. Akad. Wiss., Berlin, 6. Dec. 1894, L. (pp. 1203–1210).

the male. But how the eggs are fertilized remains to be made known. For further detailed description of nest and eggs the memoir of Möbius (1894) may be consulted.

Only the early stages of development within the egg have been observed. The later history with known means of observing and rearing the embryos and the history of the transformations the young into the familiar adult will doubtless be as remarkable as that of the angler.

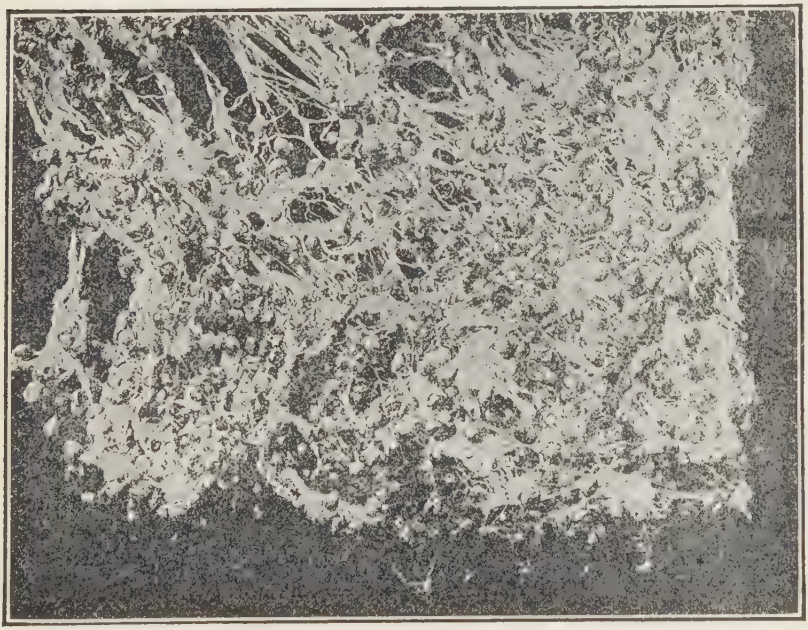


FIG. 47.—Part of supposed nest of Pterophryne magnified twice. After Möbius.

Möbius, like his predecessors, assumed that the eggs were those of *Pterophryne* and, finding that those in the ovary of one he examined were without filaments and smaller than those in the nest, postulated that probably they became provided with the polar filaments during passage through the oviducts.[a]

Sir John Murray, in the Narrative of the Voyage of H. M. S. *Challenger* (Vol. I, p. 136), also assuming that the maker was the Antennariid, declared that the nest "is composed of branches of the gulf weed bound together by means of long sticky gelatinous strings formed by the fish for this purpose, and is filled with eggs."

[a] Beide Ovarien münden in einen gemeinschaftlichen kurzen geräumigen Eileiter, in welchem wahrscheinlich die Substanz der Nestfäden secernirt wird. Op. cit., p. 8.

The spheroidal masses of seaweed continued to be credited to the *Pterophryne* by the latest and best ichthyologists. Bridge and Boulenger, in the volume on fishes of the Cambridge Natural History (vol. 7, 1904), accepted the old story as an established fact. But at last it turned out that the whole oft-repeated story was baseless, so far as the *Pterophryne* was concerned, and that it arose simply from misidentification of the eggs found in the sargasso mass.[a]

In 1905, as already remarked, there was a drift of sargasso weed with many individuals of the *Pterophryne histrio* along the eastern American coast. In August, Dr. Hugh Smith, the Deputy United States Fish Commissioner, informed the writer that he had received eggs of the fish and extended an invitation to examine them. The eggs and the data connected with them proved that the mode of oviposition of the *Pterophryne* was similar to that of the common angler. Consequently *Pterophryne* could not have been the maker of the nestlike masses ascribed to it. The writer had recently acquainted himself with the habits and oviposition of the flying fishes and, with the knowledge of what the eggs of *Pterophryne* really were, had no hesitation in declaring that the eggs described by Möbius in connection with the spheroidal masses of sargassum were in truth those of a flying fish. Further, the flying fish could have taken no part in making a nest and the form of the mass was simply the result of the automatic action of the polar filaments.

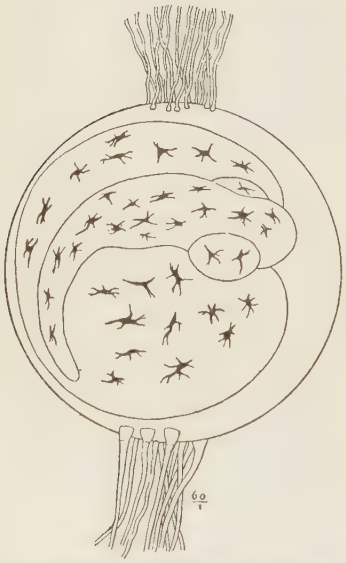


FIG. 48.- Egg of Flying fish erroneously attributed to Pterophryne, enlarged 30 times. After Möbius.

The alleged nest of *Pterophryne* was for the first time illustrated as a whole by Dr. Alexander Agassiz by an excellent and artistic figure published in 1888 in his Three cruises of the *Blake*.[b] He naturally assumed that the previous iden-

[a] The details of this discovery may be found in Science, viz, Gill, Theodore, The Sargasso fish not a nest-maker, Dec. 22, 1905, p. 841; Gudger, E. W., A note on the eggs and egg-laying of *Pterophryne histrio*, the Gulf-weed fish, Dec. 22, 1905, p. 841–843; Gill, Theodore, The work of Pterophryne and the Flying-fishes, Jan. 11, 1907, p. 63; Smith, Hugh, Supplementary Remarks, pp. 63–64. See also Smithsonian Report for 1905, 1907, pp. 407–408, where illustration of "nest" by A. Agassiz is given.

[b] Agassiz, Alexander. A Contribution to American Thalassography.—Three cruises of the United States Coast and Geodetic Survey Steamer "Blake," [etc.], from 1877 to 1880. Boston and New York, 1888. (Fig. of "nest," vol. 2, p. 31.)

tification was correct and merely noted that the "*Pterophryne*, 'the marbled angler' of the Sargasso Sea, is especially adapted to live among the floating algæ, to which it clings with its pediculated fins, and in which it intertwines its gelatinous clusters of eggs."

Professor Agassiz, in his original article, did not notice any filaments connected directly with the eggs he observed, and the present writer thought that it was possible that some of the real eggs of a disintegrated *Pterophryne's* raft might have drifted against a flying fish's conglomeration. The difference in the times of oviposition of the two fishes was, it is true, a serious objection to such an hypothesis, but it was barely possible that the time of oviposition of a *Pterophryne* might have been so delayed that a conjunction of the two fishes might have occurred. Doctor Agassiz kindly responded to an appeal for information by sending a couple of eggs taken from the exterior of the "nest" and they were found to have the polar filaments characteristic of the flying fish's eggs.

FIG. 49.—Front view of the head and rostral region of *Cœlophrys brevicaudata*. After Brauer. See p. 597.

THE BIRDS OF INDIA.[a]

By Douglas Dewar, F. Z. S., I. C. S.

Of the birds of India it may truly be said "their name is legion." He who would treat of them in a short paper must perforce confine himself to generalities. I therefore propose to devote the time at my disposal, firstly, to a consideration of the general characteristics of the avifauna of India, and then to pass on to some aspects of the study of bird life.

Literary critics seem to be agreed that we who write about Indian birds form a definite school. "Phil Robinson," they say, "furnished thirty years ago a charming model, which all who have followed him seem compelled to copy more or less closely." Mr. W. H. Hudson remarks:

> We grow used to look for funny books about animals from India just as we look for sentimental natural history books from America.

In a sense this criticism is well founded. Popular books on Indian ornithology resemble one another in that a ripple of humor runs through each. But the critics err when they attempt to explain this similarity by asserting that Anglo-Indian writers model themselves, consciously or unconsciously, on Phil Robinson, or that they imitate one another.

The mistake made by the critics is excusable. When each successive writer discourses in the same peculiar style the obvious inference is that the later ones are guilty of more or less conscious plagiarism. But such an inference is drawn only by those who have not enjoyed the advantage of meeting our Indian birds in the flesh. To those who do possess this advantage it is clear that the birds themselves are responsible for our writing being funny. We naturalists merely describe what we see.

The avifauna of every country has a character of its own. Mr. John Borroughs has remarked that American birds as a whole are more gentle, more insipid than the feathered folk of the British Isles.

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[a] Reprinted by permission, with author's corrections, from Journal of the Royal Society of Arts, London, No. 2927, Vol. LVII, December 25, 1908.

Still greater is the contrast between English and Indian birds. The latter are to the former as wine is to water.

India is peculiarly rich in birds of character. It is the happy hunting ground of that unique fowl, *Corvus splendens*—the splendid crow—splendid in sagacity, resource, adaptiveness, boldness, cunning, and depravity—a veritable Machiavelli among birds. I might almost say a super-bird.

The king crow (*Dicrurus ater*) is another creature which can be described only by superlatives. He is the Black Prince of the bird kingdom—the embodiment of pluck. The thing in feathers of which he is afraid has yet to be evolved. Like the mediæval knight, he goes about seeking those upon whom he can perform some small feat of arms. In certain parts of India he is known as the "Kotwal"—the official who to many stands forth as the embodiment of the might and majesty of the British raj.

When we turn to consider the more outward characteristics of birds, the peacock (*Pavo cristatus*), the monal pheasant (*Lophophorus refulgens*), the so-called "blue jay" (*Coracias indica*), the oriole (*Oriolus kundoo*), the white-breasted kingfisher (*Halcyon smyrnensis*) the sunbird (*Arachnechthra zeylonica*), the little green bee-eater (*Merops viridis*), and a host of others rise up before us. Of these some, showily resplendent, compel attention and admiration: others, of quieter hues, possess a beauty which can not be appreciated unless they be held in the hand and minutely examined, for each of their feathers is a poem of exquisite beauty.

At the other extreme stands the superlative of avian hideousness, the ugliest bird in the world—*Neophron ginginianus*, the scavenger vulture. The bill, the naked face, and the legs of this creature are a sickly yellow. Its plumage is dirty white, with the exception of the ends of the wing feathers, which are a shabby black. Its shape is displeasing to the eye; its gait is an ungainly waddle. Nevertheless, such is the magic of wings, even this fowl looks almost beautiful as it sails, on outstretched pinions, high in the heavens.

THE HORNBILL.

Between the extremely beautiful and the extremely ugly birds we meet with another class having superlative attributes—the extremely grotesque. This class is well represented in India. The great hornbill (*Dichoceros bicornis*) and the adjutant (*Leptoptilus dubius*) are birds which would take prizes in any exhibition of oddities. The former is nearly 4½ feet in length. The body is only 14 inches long, being an insignificant part of the bird, a mere connecting link between the massive beak and the great loosely-inserted tail. The beak is nearly a foot in length, and is rendered more conspicuous than it

would otherwise be by a structure known as a "casque." This is a horny excrescence, nearly as large as the bill, which causes the bird to look as though it were wearing a hat, which it had placed for a joke on its beak, rather than its head. The eye is red, and the upper lid is fringed with eyelashes, which add still further to the oddity of the bird's appearance. The creature has an antediluvian air, and one feels, when contemplating it, that its proper companions are the monsters that lived in prehistoric times. The actions of the hornbill are in keeping with its appearance. Each morsel of food is tossed into the air and caught in the bill preparatory to being swallowed. Mr. E. V. Lucas describes the hornbill as the best short slip in the Zoological Gardens. Hornbills are the clowns of the forest.

THE ADJUTANT.

Even more grotesque is the adjutant. This is a stork with an enormous bill, a tiny head, and a long neck, all innocent of feathers. From the front of the neck hangs a considerable pouch, which the bird can inflate at will. Round the base of the neck is a ruff of white feathers that causes the bird to look as though it had donned a lady's feather boa.

It is the habit of the adjutant to stand with its head buried in its shoulders, so that, when looked at from behind, it resembles a hunch-backed, shriveled-up old man wearing a gray swallow-tailed coat. It looks still more ludicrous when it varies the monotony of life by kneeling down. Its long shanks then stretch out before it, giving the impression that they have been mistakenly inserted hind part foremost. Its movements partake of the nature of a cake-walk. Lockwood Kipling writes:

> For grotesque devilry of dancing the Indian adjutant beats creation. Don Quixote or Malvolio was not half so solemn or mincing, and yet there is an abandonment and lightness of step, a wild lift in each solemn prance which are almost demoniacal. If it were possible for the most angular, tall, and demure of elderly maiden ladies to take a great deal too much champagne and then to give a lesson in ballet dancing, with occasional pauses of acute sobriety, perhaps some faint idea might be conveyed of the peculiar quality of the adjutant's movements.

If the hornbill be the clown of the forest, the adjutant is the buffoon of the open plain.

AVIAN CRAFTSMANSHIP.

When we turn to avian craftsmanship we find no lack of skilled workmen among our Indian birds. The famous weaver bird (*Ploceus baya*) and the less well-known wren warbler (*Prinia inornata*) are past masters of the art of weaving. The tailor-bird (*Orthotomus su-*

torius), as its name implies, has brought the sartorial art to a pitch of perfection which is not likely to be excelled by any creature which has no needle other than its beak.

The nests of the various species of orioles are in their way quite as wonderful as those of the tailor-bird. Each is a hammock slung by means of strong fibers (frequently strips of the pliable bark of the mulberry tree) to a forked branch in much the same manner as a prawn net is secured to its wooden framework.

SONG BIRDS.

If there be any characteristic which Indian birds do not possess to a degree it is perhaps the ability to sing. A notion is abroad that the birds of Hindustan can not sing, that they are able to scream, croak, and make all manner of weird noises; but to sing they know not how. This idea perhaps derives its origin from Charles Kingsley, who wrote:

> True melody, it must be remembered, is unknown, at least at present, in the Tropics, and peculiar to the races of those temperate climes into which the song birds come in spring.

This is, of course, absurd.

Song birds are numerous in India. They do not make the same impression upon us as do our English birds, because, firstly, we are older and therefore less impressionable when we first hear them; and, secondly, their song has not those associations which render dear to us the melody of birds in the homeland. Further, there is nothing in India which corresponds to the English spring, when the passion of the earth is at its highest, because there is in India no sad and dismal winter time, when life is sluggish and feeble.

The excessive joy, the rapture, the ecstasy with which we greet spring in the British Isles is, to a certain extent, a reaction. There suddenly rushes in upon the songless winter a mighty chorus, a tumult of birds, to which we can scarcely fail to attach a fictitious value.

India possesses some song birds which can hold their own in any company. Were the shama (*Cittocincla macrura*), the magpie robin (*Copsychus saularis*), the fantailed flycatcher (*Rhipidura albifrontata*), the orange-headed ground thrush (*Geocichla citrina*), the white eye (*Zosterops palpebrosa*), the purple sunbird (*Arachnechthra asiatica*), and the bhimraj (*Dissemurus paradiseus*), to visit England in the summer, they would supplant, in popular favor, some of our English song birds.

FEARLESSNESS OF INDIAN BIRDS.

Indian birds generally are characterized by their fearlessness of man. It were easy to occupy a whole hour in citing examples of this.

A few must suffice. Pied wagtails (*Motacilla maderaspatensis*), brown rock chats (*Cercomela fusca*), which some believe to be the "sparrows" of Scripture, sparrows proper, mynas (*Acridotheres tristis*), spotted owlets (*Athene brama*), doves (*Turtur cambayensis*), roller birds (*Coracias indica*), tits (*Parus monticola*), swifts (*Cypselus affinis*), and robins (*Thamnobia cambaiensis*), have all, at some time or other, elected to share my bungalow with me, building in the walls, under the roof of the veranda, or on a window ledge. Similarly hoopoes (*Upupa indica*) and magpie robins (*Copsychus saularis*) frequently have nested in holes in the mud walls of servants' houses in the compound. Tailor birds (*Orthotomus sutorius*), sunbirds of two species (*Arachnechthra asiatica* and *A. zeylonica*) and bulbuls of three (*Molpastes hæmorrhous*, *M. bengalensis*, and *M. intermedius*) have constructed their nests amid the leaves of plants growing in pots on my veranda. In the garden, within 30 or 40 yards of the house, the following have brought up their families: Ring doves (*Turtur risorius*), paradise flycatchers (*Terpsiphone paradisi*), fantailed flycatchers (*Rhipidura albifrontata*), house crows (*Corvus splendens*), corbies (*Corvus macrorhynchus*), tree pies (*Dendrocitta rufa*), crow pheasants (*Centropus sinensis*), paddy birds (*Ardeola grayi*), green barbets (*Thereiceryx zeylonicus*), coppersmiths (*Xantholæma hæmatocephala*), woodpeckers (*Brachypternus aurantius*), green parrots (*Palæornis nepalensis* and *P. torquatus*), shikras (*Astur badius*), kingfishers (*Halcyon smyrnensis*, *Alcedo ispida*, and *Ceryle rudis*), babblers (*Crateropus canorus* and *Argya caudata*), kites (*Milvus govinda*), orioles (*Oriolus kundoo*, *O. melanocephala*), king crows (*Dicrurus ater*), and others which I either omitted to notice or fail to recollect.

Verily is the Indian avifauna one of superlatives. Judging from what I have read of the feathered folk that inhabit other parts of the world, it seems to me that the birds of India are more interesting than those of America, Africa, or Australia, and infinitely more so than the poverty-stricken collection found in Europe. This opinion, I would add, is shared by Mr. Frank Finn, whose knowledge of the birds of the world is as great as that of any man living.

WEALTH OF SPECIES.

Not the least important feature of the avifauna of India is its wealth of species. Oates and Blanford describe over sixteen hundred of these. Among Indian birds are numbered 108 different kinds of warbler, 56 woodpeckers, 30 cuckoos, the same number of ducks, 28 starlings, 17 butcher birds, 16 kingfishers, and 8 crows.

The richness of the fauna is accounted for by the wide differences in the climate of the various provinces of India, and by the fact

that India lies in two of the great divisions of the ornithological world. The Himalayas form part of the Palæarctic region, while the plains are included in the oriental region.

The feathered folk that dwell in the mountains and valleys of the Himalayan range differ as widely from the denizens of the plains as do the birds of England from those of Africa. The 30-mile tonga journey from Rawalpindi to Murree transports the traveler from one bird realm to another. In hot, parched, dusty Pindi the most noticeable birds are the kites, sparrows, house crows, mynas, rose-ringed and Alexandrine paroquets, Indian hoopoes, and rollers, bee eaters, paddy birds, tailor birds, rat birds, molpastes bulbuls, king crows, ring doves, little brown doves, orioles, spotted owlets, the "seven sisters," koels (*Eudynamis honorata*), robins, white breasted kingfishers, golden-backed woodpeckers, scavenger vultures, and fantailed and paradise flycatchers.

Of all these, the kites, orioles, mynas, fantailed flycatchers, and scavenger vultures are the only ones seen on the well-wooded Murree hills. There, instead of the caw of the house crow the deeper note of the corby is heard. The crescendo shriek of the koel is replaced by the pleasing double note of the European cuckoo (*Cuculus canorus*). For the eternal "coo-coo-coo" of the ring (*Tutur risorius*) and the little brown doves, the "kokla kokla" of the kokla green pigeon (*Sphenocercus sphenurus*) is substituted. The chuckles and cackles of the spotted owlet no longer cleave the night air, but the silence of the darkness is broken by the low, monotonous whistle of the collared pigmy owlet (*Glaucidium brodiei*). The boisterous rose-ringed and Alexandrine paroquets are replaced by their slaty-headed cousins (*Palæornis schisticeps*).

The golden-backed woodpecker, the king crow, the coppersmith, the Indian hoopoe, the gray partridge (*Francolinus pondicerianus*), and the Molpastes bulbuls are supplanted in the Himalayas by pied woodpeckers (*Dendrocopus himalayensis*), the ashy drongo (*Dicrurus longicaudatus*), the great Himalayan barbet (*Megalæma marshallorum*), the European hoopoe (*Upupa epops*), the chukor (*Caccabis chucar*), and the black bulbul (*Hypsipetes psaroides*). Some birds found in the plains have no Himalayan counterparts, but as a set-off we find many new forms on the mountains, as, for example, the various jays, laughing thrushes, tits, warblers, the white-capped (*Chimarrhornis leucocephalus*) and the plumbeous (*Rhyacornis fuliginosus*) redstarts, the grosbeaks, the ouzels, rock thrushes, greenfinches, pheasants, and the woodcock (*Scolopax rusticula*). But I must refrain from further cataloguing.

How greatly the avifauna of the Himalayas differs from that of the plains is demonstrated by a comparison of the nesting expe-

riences of Colonel Rattray, in the Murree hills, and myself, at Lahore, which may be taken as typical of the plains of the Punjab. In the course of two years' observation Colonel Rattray found nests of 104 species of birds. I did not keep a record of the two years I spent at Lahore, but I think I may safely say that I saw the nests of over 60 species of birds, and of these only seven are included in Colonel Rattray's list, published in the Journal of the Bombay Natural History Society. Nor is this all. The Himalayas have what Jerdon calls a "double fauna." The birds of the eastern portion are common to the Himalayas and to the hilly regions of Assam and Burma, while those found on the western portion of the range include a large number of European species, and are, to a large extent, common to the Himalayas and to Tibet and Northern Asia. Then, again, the Malabar Coast and the Nilgiris possess not a few species of birds found nowhere else. It is, therefore, possible to divide the Indian Empire into four geographical regions, each having a distinctive avifauna. Such, then, are the birds that render India an El Dorado for the naturalist.

Let us now consider them from three different standpoints. Firstly, from that of the bird-lover, of him who watches the feathered folk chiefly, if not solely, on account of the pleasure he derives from so doing. Then from the standpoint of the biologist, who studies the fowls of the air, as he studies other forms of life, in the hope of elucidating some of the mysteries presented by the natural universe. Lastly, from the utilitarian standpoint of the economist, who concerns himself with birds in order to determine how they may be made to serve best the interests of man.

THE CHARM OF BIRDS.

Mr. W. H. Hudson quotes Sir Edward Grey as saying that the love and appreciation and study of birds is something fresher and brighter than the second-hand interests and conventional amusements in which so many in these days try to live; that the pleasure of seeing and listening to them is purer and more lasting than any pleasures of excitement, and, in the long run, "happier than personal success."

Only those who have come under the sway of the charm of birds can appreciate to what an extent the joie de vivre is enhanced by an acquaintance with them. Interest in the feathered hosts, when once aroused in a man, will never flag or wane. Rather will it grow in intensity with advancing years, so that many a man as—

> Swift to its close ebbs out life's little day,

has been able to say, with the late Mr. R. Bosworth Smith, "birds have been to me the solace, the recreation, the passion of a lifetime."

It is not easy to describe in words the nature of the enduring happiness which the love of birds gives. This must, of necessity, vary with temperament. Says Gilbert White:

> To yonder bench, leaf-shelter'd, let us stray,
> Till blended objects fail the swimming sight,
> And all the fading landscape sinks in night;
> To hear the drowsy dor come brushing by
> With buzzing wing, or the shrill cricket cry;
> To see the feeding bat glance through the wood;
> To catch the distant falling of the flood;
> While o'er the cliff th' awakened churn-owl hung
> Through the still gloom protracts his chattering song;
> While high in air, and pois'd upon his wings,
> Unseen, the soft enamor'd woodlark sings:
> These, nature's works, the curious mind employ,
> Inspire a soothing, melancholy joy:
> As fancy warms, a pleasing kind of pain
> Steals o'er the cheek, and thrills the creeping vein.

There are occasions on which watching birds has inspired in me "a soothing, melancholy joy." But, as a rule, the pleasure which the feathered folk give me, is of a more lively and exhilarating nature, not infrequently culminating in mirth and laughter. For this, the birds of India are largely responsible. As I have said elsewhere, the man who can watch the doings of the Indian crow for half an hour without being provoked to laughter should, without delay, apply for six months' leave on medical certificate.

I am sometimes asked, Wherein lies the attraction of birds?

The reply is: "In their sprightliness, their vivacity, their beauty, and their grace." As Mr. F. W. Headley justly observes, "a bird seems to have more life in him than any other living creature."

In a sense birds stand at the head of creation. It is on them that nature has showered a double portion of her good things. Their power of flight gives them a big advantage over their terrestrial fellow-creatures. Professor Newton wrote:

> Birds have no need to lurk hidden in dens, or to slink from place to place under the shelter of the inequalities of the ground or of the vegetation which clothes it, as is the case with so many animals of similar size.

This locomotive superiority, although it must add greatly to the happiness of the life of a bird, has not been all gain. Animals are so constituted that it is only through intense struggle that they advance toward perfection. The fowls of the air, safe in their power of flight, have not been obliged to use their wits to the extent that terrestrial creatures have. Instead of developing a large brain, they have dissipated their energy in flight, song, and gorgeous plumage. Birds form a backwater in the stream of evolution.

THE SCIENTIFIC STUDY OF BIRDS.

I have already dwelt upon the richness of the avifauna of India. It is this wealth in number and variety of species which makes it so valuable to the biologist.

Grant Allen has said somewhere that there is no university like the Tropics, that no man can be said to be properly educated who has not passed the tropical tripos.

It is significant that the idea of natural selection came to both Darwin and Wallace in the Tropics. This great hypothesis revolutionized biology. But since Darwin's day the science has made comparatively little progress. This appears to be in great part due to the comparative poverty of the European fauna. The Americans are more fortunate in this respect. But in the New World the progress of biological science has been greatly hindered by the prevailing belief in America, not only that acquired characteristics are capable of inheritance, but that their inheritance has played an important part in evolution.

Whether or no the explanations I suggest are the correct ones, the fact remains that of late years biology has not made progress commensurate with the impetus given it by the publication of Darwin's Origin of Species.

Nearly half a century ago Jerdon wrote in the introductory chapter to his Birds of India:

> The tendency of the present age is to accumulate facts and not to generalize, but we have now a sufficiency of facts and want our Lyall to explain them.

Since Jerdon's day things have changed. At present we are almost overwhelmed by theories. Many of these possess little or no value, because they are founded on an insufficient basis of fact. Day by day fresh theories are published, which would not have been enunciated had their originators graduated in the university of the Tropics.

As an example of the kind of absurdities to which theorizing on insufficient evidence leads, I may cite Doctor Jenner's explanation of the parasitic habits of the cuckoo. He conjectured that the short stay which cuckoos made in England is the true reason why they do not bring up their own young, as the parent birds would be impelled, by a desire to migrate, to quit their progeny before they were able to provide for themselves. Had that eminent medical man paid a visit to India and studied the habits of the commonest cuckoo, the koel, he would not have formulated this theory. The koel stays for over six months in those localities where it breeds, so that there can be no question of its having sufficient time to rear up its young.

NEO-DARWINISM.

The growth of what is known as "Neo-Darwinism" is a striking example of the modern tendency to theorize on insufficient evidence. A large school of biologists, headed by Doctor Wallace and Professor Weismann, declares that all the varied phenomena of the organic world can be explained by the action of natural selection on indefinite and indeterminate variations. I venture to submit that Wallace and Weismann would have but few followers had our European naturalists the advantage of an intimate acquaintance with the birds of India.

Come with me in imagination to a wood on the Nilgiri hills and let us rest there a little, sheltered by the foliage from the rays of the sun, and listen to the voices of the birds. The joyous notes of the bulbuls (*Otocompsa fuscicaudata*) fall unceasingly on the ear, forming the dominant note of the bird choir. Upon these are superimposed a tumult of other sounds—the curious call of the scimitar babbler (*Pomatorhinus horsfieldii*), the mirthful tones of the laughing thrush (*Trochalopterum cachinnans*), the sweet little song of the white-browed, fantailed flycatcher, the softer lay of Tickell's flycatcher (*Cyornis tickelli*), the cheeping of the black and orange species (*Ochromela nigrirufa*), the feeble twitters of the gray-headed one (*Culicicapa ceylonensis*), and a multitude of other sounds.

THE PARADISE FLYCATCHER.

While we are listening a fairylike bird flits silently into view and perches in a leafy tree. This is a paradise flycatcher—a cock in the full glory of his adult plumage. Jet black is his crested head, contrasting sharply with his snowy plumage. Two of his tail feathers, 12 inches longer than the others, hang down like satin streamers. The hen lacks this ornament, and is deep chestnut, where her lord and master is white. While we are contemplating him another cock appears on the scene, but he, although possessing the two long tail feathers, is rich chestnut in color, as is the hen. He is in the second year of his existence, but, like his white neighbor, has a wife and a nest on which he spends much of the day. Paradise flycatchers are restless creatures, constantly on the move. These two are soon lost to view amid the green foliage.

But another bird, in its way equally beautiful, has appeared on the scene. Having taken some tiny insect upon the wing, it has alighted on a horizontal branch, and is now bowing gracefully to right and to left, the while spreading out its tail into a fan and singing its lay, which has been likened to the opening bars of the "Guard's Valse." This is the white-browed, fantailed flycatcher. We can not say whether it is a cock or hen, for in this species there is no external difference

between the sexes. But its habits are very similar to those of the paradise flycatcher and, like that form, it builds an open, cup-shaped nest. From the same tree a gray-headed flycatcher makes a sally into the air after the "circling gnat." He must have been sitting there some time, but, being inconspicuous, he escaped our notice until he moved.

Let us now saunter on a little, keeping our eyes open for other species of flycatcher, because it is these we particularly wish to see. In one tree we notice, picking insects off the leaves, a flock of minivets (*Pericrocotus flammeus*), the cocks arrayed in black and flaming red, while the hens look equally gay in their gowns of black and bright yellow. On one of the lower branches of the same tree we notice a dumpy little bird with a short square tail, robin-like in coloring, but very unrobin-like in shape. It suddenly takes to its wings, circles after some tiny insect, and returns to its perch, and thus we are able to recognize it as the black-and-orange flycatcher. The sexes being alike in plumage, we can not say to which one this individual belongs.

A sharp "chick, chick," followed by a little tune of six notes, betrays the presence of a Tickell's blue flycatcher. Approaching softly the tree whence the song seems to come, we soon discover the exquisite little glistening blue red-breasted songster.

We have now seen all the common flycatchers of the Nilgiris save the blue one (*Stoparola albicaudata*), and it is not long before we come upon him. He is an indigo-colored bird, with whitish underparts. Going a little farther we come upon the brownish-olive hen, with three youngsters, which are brown, spotted with yellow.

THE INSUFFICIENCY OF NATURAL SELECTION.

Thus we have seen, living together in one wood, no fewer than six different species of flycatcher, of various shapes and sizes; in some the sexes are alike, in others they display considerable difference. The feeding habits of all are very similar. All dwell in the same environment. There are, indeed, differences in their various nesting habits, but those of the paradise and fantailed species are identical, so that if the coloring of a bird is solely due to the action of natural selection, these two species should be almost identical in shape, size, and coloration. Obviously, then, natural selection fails here to accomplish all that the neo-Darwinians require it to do. It explains much, but not everything. It is but one of many factors in the making of species.

INDIAN ROBINS.

The Indian robins present even greater difficulties to those who profess to pin their faith to the all-sufficiency of natural selection. Robins

are found in nearly all parts of India, and fall into two species, the brown-backed (*Thamnobia cambaiensis*) and the black-backed Indian robin (*Thamnobia fulicata*). The former occurs only in northern India, and the latter is confined to the southern portion of the peninsula. The hen of each species is a sandy-brown bird with a patch of brick-red feathers under the tail, so that we can not tell by merely looking at a hen to which of the two species she belongs. The cock of the South Indian form is, in winter, a glossy black bird, with a white bar in the wing and the characteristic red patch under the tail. The cock of the northern species, as his name implies, has a sandy-brown back, which contrasts strongly with the glossy black of his head, neck, and underparts. In summer the cocks of the two species grow more like one another, owing to the wearing away of the outer edges of their feathers; but it is always possible to distinguish between them at a glance. The two species meet at about the latitude of Bombay. Oates states that in a certain zone, from Ahmednagar to the mouth of the Godaveri Valley, both species occur, and they do not appear to interbreed.

It seems impossible to maintain that natural selection, acting on minute variations, has brought about the divergence between these two species. Even if it be asserted that the difference in the color of the feathers of the back of the two cocks is in some way correlated with adaptability to their particular environment, how are we to explain the fact that in a certain zone both species flourish?

BULBULS.

A similar phenomenon is furnished by the red-vented bulbuls. This genus falls into several species, each corresponding to a definite locality and differing only in details from the allied species, as, for example, the distance down the neck to which the black of the head extends. There is a Punjab red-vented bulbul (*Molpastes intermedius*), a Bengal (*Molpastes bengalensis*), a Burmese (*Molpastes burmanicus*), and a Madras (*Molpastes hæmorrhous*) species.

It does not seem possible to maintain the contention that these various species are the products of natural selection, for that would mean if the black of the head of the Punjab species extended farther into the neck the bird could not live in that part of the country. As there seems to be some intercrossing between these so-called species at places, such as Lucknow, where they meet, I am inclined to regard them as local races of a species, rather than as species of a genus. This, however, does not affect the difficulty which they present to Wallace and his school.

It is tempting to believe that these slight external differences are in some way or other produced by the direct action of the climate to

which the various forms are subjected. Unfortunately for this hypothesis, there is evidence which seems to disprove it. For example, the common house-sparrow in India differs from our English sparrows in having white cheeks, but those Indian sparrows which are brought to this country do not lose the white cheek patch as they should do had it been the result of the direct action of the climate in India.

THE RED TURTLE DOVE.

The red turtle dove (*Oenopopelia tranquebarica*) is another Indian bird of great interest to the biologist. It is widely distributed over the plains, and undergoes local migration. Its nesting and feeding habits are identical with those of the other doves common in India—the ring, the spotted, and the little brown dove. But, while in these species the cocks and the hens are alike in external appearance, the red turtle dove displays considerable sexual dimorphism. So great is the difference between the cock and the hen that they have been mistaken for different species. Thus we have in India, living side by side, four widely distributed species of dove, all having similar habits, and in three of these species the sexes are alike in appearance, while in the fourth they display considerable differences. Why this should be so, no neo-Darwinian has attempted to explain. Facts such as these seem to be left severely alone by Weismann and his followers.

SO-CALLED MIMICRY.

The avifauna of India furnishes zoologists with what some, at any rate, of them are pleased to term a most striking case of mimicry. Among birds and beasts certain species have their doubles. Now, when two species, which are not near blood relations, are alike in appearance, and this likeness appears to be advantageous to one of the two species, this latter is said in biological parlance, to mimic the other. Such mimicry is, of course, unconscious. It is commonly supposed to have been brought about by natural selection. Now, there is in India a cuckoo—the drongo-cuckoo (*Surniculus lugubris*)—which resembles in appearance the common king-crow (*Dicrurus ater*). Further, the cuckoo is parasitic on the king-crow. This last is, as we have seen, a very pugnacious bird, especially at the nesting season. It guards its nursery with great ferocity. I have watched a pair of these little birds attack and drive away a monkey which tried to climb into the tree in which their nest was placed. Indeed, so able a fighter is the king-crow that some other birds, notably orioles and doves, which also are very pugnacious, frequently build their nests in the same trees as the king-crow, in order to share the benefit of his prowess. It would be almost impossible to deposit eggs in the nest of a bird so pugnacious as the king-crow without resorting

to guile. But the drongo-cuckoo is as like the king-crow in appearance as one pea is like another. Both are small, glossy, black birds with a longish forked tail. Zoologists, seeing how the cuckoo profits by this resemblance, declare that it mimics the king-crow, and that this resemblance has been brought about by natural selection. The theory sounds very plausible, but close inspection reveals its weak points. The king-crow is no fool, so that in order that the cuckoo may delude him into the belief that it is a fellow king-crow the likeness must be fairly close. But as the average cuckoo is not in the least like the king-crow in appearance, no small variation in the direction of king-crow appearance would be of any use to it. Hence this remarkable resemblance must in the first place have arisen fortuitously, or rather, causes similar to those which effected the nigritude of the king-crow must have made the ancestral drongo-cuckoo black. But we are as yet more or less in the dark as to what has caused the king-crow to be black, so that we are not in a position to say how it was that this species of cuckoo came to resemble the drongo in appearance.

In attempting to account for any characteristic of an organism by means of natural selection we must be able to explain the utility to the organism of the character in question in its initial stage, and at each subsequent stage of its development. It is not sufficient to show that the character in its final and complete stage of use to its possessor. This is an important point which biologists, especially neo-Darwinians, frequently seem to forget.

The black-and-yellow grosbeak (*Pyenorhamphus icteroides*), a bird common in many parts of the Himalayas, resembles the black-headed oriole nearly as closely as the drongo-cuckoo does the king-crow. But since the grosbeak does not descend to the plains and the black-headed oriole (*Oriolus melanocephalus*) does not ascend the hills, neither can possibly derive any benefit from the resemblance, which, it should be added, extends only to the cocks. Thus there is here no question of mimicry.

Another Indian cuckoo, the famous brain-fever bird (*Hierococcyx varius*), displays a remarkable likeness to the shikra (*Astur badius*), a sparrow-hawk very common in India. This is said to be a case of mimicry, because the cuckoo is supposed to derive profit from the resemblance. The babblers (*Crateropus canorus*), which it victimizes, are said to mistake it for a shikra, flee in terror from it, and so give it the opportunity it requires to gain access to their nests. It is quite likely that the cuckoo does derive benefit from the resemblance. But this is not sufficient to explain a likeness which is so faithful as to extend to the marking of each individual feather. When a babbler espies a hawk-like bird, it does not wait to inspect each feather before fleeing in terror; hence all that is necessary to the cuckoo is

that it should bear a general resemblance to the shikra. The fact that the likeness extends to minute details in feather marking point to the fact that in each case identical causes have operated to produce this type of plumage.

WALLACEISM.

It is thus obvious that the problem of evolution is far more complex than Wallace and Weismann would have us believe. Since their doctrine is widely accepted in England to-day and is inculcated by Professor Poulton at Oxford, I have, in touching upon the study of the birds of India in its scientific aspect, thought fit to bring together a few facts which seem to show that the neo-Darwinian position is untenable. I would add that I went out to India imbued with the teaching of Wallace, and have abandoned it with reluctance, owing to the many facts opposed to it that have forced themselves upon my notice in that country. I am not attacking the doctrine of natural selection, for I believe that selection is an important factor in the genesis of species. It is to the views of Wallace and Weismann, who have out-Darwined Darwin, that I am compelled to take exception. It seems to me that Dr. Wallace preaches, not Darwinism, but Wallaceism, which is a very different thing.

ECONOMIC ORNITHOLOGY.

The economic aspect of the study of the birds of India is the one likely to commend itself most to the members of this society. It is certainly the most important from a practical point of view. Unfortunately it is the aspect with which I am the least familiar, since I study birds purely as a hobby.

I take it that all men are agreed that birds as a whole are of incalculable value to man. Were they to disappear from off the face of the earth human existence would be impossible. As things are, insects constitute the dominant group of organisms.

> In number of species—

writes Mr. Maxwell-Lefroy, imperial entomologist to the government of India—

> in actual numbers or bulk, in the sum total of their activities, they outweigh all other forms of animal life at present on the earth.

They take toll of all other creatures. The birds are their chief foes. It is due almost entirely to the efforts of the fowls of the air that insects are held in check. To quote Mr. Maxwell-Lefroy again:

> Birds are the fluctuating check on insect life, the safety valve as it were; they congregate where they find insects, regardless of their species or habits, and constantly consume the superfluous and superabundant insect life.

But all birds are not equally useful to man. Some are commonly supposed to be positively harmful. Hence the economist does not look upon all with equal favor. He divides the fowls of the air into two classes—the friends and the foes of man. His policy is obviously to encourage the former and to repress the latter.

Unfortunately, it is by no means always easy to determine into which category a particular species falls. A great many birds, as, for example, flycatchers, feed exclusively on insects, and since these latter may as a whole be regarded as man's most deadly enemies, it follows that all purely insectivorous birds are his very good friends. On this point there can be no difference of opinion. Nor can anyone doubt that those fowls of the air which subsist mainly on insects are of great utility to man.

Mr. Maxwell-Lefroy writes in his Indian Insect Pests:

> A large number of birds are wholly insectivorous, a large number are partly so, and every one of these deserves protection and encouragement.

In other words, the great majority of birds are useful to man.

FRIENDS OR FOES?

But there exists a multitude of feathered creatures that are not purely insectivorous. There are the raptores, which devour other birds, small mammals and reptiles; the vultures which eat carrion; and the birds which feed largely on fruit, grain, or fish. How are these to be regarded? This is a question which can be satisfactorily answered only by considering each species separately, and ascertaining the nature of its food at different stages of its existence, and under various conditions, as, for example, in seasons of drought or excessive rainfall, or at times when the country is invaded by some insect pest, such as the locust. Even when we have succeeded in ascertaining this, we are by no means always able to say whether the bird in question is a friend or foe. Let us, for example, suppose that the species under observation lives chiefly upon grain crops, but that it feeds its young on harmful caterpillars. The caterpillar is a voracious creature, which consumes several times its own weight of food in the course of a day. Thus, the devouring of a caterpillar is a work of merit, which will outweigh the injury done by eating a considerable number of food grains, but who is to say how many food grains go to a caterpillar?

THE SPARROW.

Take the common sparrow—a bird which has, of late, come in for much abuse in the columns of The Times. It is of great importance to determine the policy to be adopted toward him, for he has spread himself over the greater part of the world. In India he is almost as

abundant as in England. If the question: Friend or foe? were determined by votes, I fear that the pushing little fellow would be condemned by a large majority, but I am not at all sure that his condemnation would be just.

We must bear in mind that the sparrow, as his scientific name, *Passer domesticus*, suggests, is a bird of towns rather than of the open country. Now, a town sparrow can not do much damage to the crops, unless, of course (as many London sparrows are said to do), he takes a holiday in the country at the time when the corn is ripening!

SPARROW NESTLINGS.

We must not forget that young sparrows in the nest are fed chiefly on insect food. Last year I placed in a cage in the veranda some baby sparrows taken out of a nest in the pantry of my bungalow. The parents soon found them out, and fed them through the bars of the cage. I was able to satisfy myself that the young were fed largely on green caterpillars, which I believe were captured in the kitchen garden. In each beakful of food carried to the young bird there were not less than three of these caterpillars. By watching the number of times food was taken to the cage, I calculated that the hen, for she does the lion's share of the feeding, brought in something like 540 insects (chiefly caterpillars) per diem to her brood. She fed them on this diet for nearly three weeks, so that the young ones before leaving the nest had swallowed between them several thousands of caterpillars.

Now, we know that the rearing of a family seems to be the normal condition of a sparrow, so that this species performs a very great service to man in the form of insect destruction. Further, the adult birds sometimes eat insects, and this they are likely to do whenever, from some cause or other, insects become unusually abundant, that is to say, precisely at the time when it is most important to man that his little six-legged foes should be devoured. As a set-off to this we must not forget the large amount of food grains that sparrows devour. Moreover, were they less numerous, their place might perhaps be taken by birds of more undoubted utility to man. Probably the only method of arriving at the truth as regards the sparrow is to exterminate him completely from a given locality, and watch the results. This, I believe, was done about forty years ago in Maine and Auxerre, with the result that almost every green leaf was destroyed by caterpillars in the following year.

It is thus obvious that the determination of the economic value of some birds is not by any means a simple matter. One thing is certain, and that is that no bird should be condemned as an enemy of man until a prolonged and careful inquiry into its habits has been made.

Running through the long list of Indian birds, we meet with some twenty species which the economic ornithologist might perhaps class as "doubtful" birds which certainly do devour food crops, and which must consequently be classed as foes unless they render some service to man by way of compensation for the damage they do. These are the sparrows, the various species of crow, the rose-colored starling, some of the larger finches, the paroquets, the doves, and the geese.

THE CROWS.

With the sparrow we have already dealt. The crows look upon the ripening crops as a feast prepared for their benefit. But grain forms quite an insignificant portion of their menu. They prefer the dust bin to the field, the town to the country. The corvi are a source of annoyance to man rather than an economic pest. They are useful, if impertinent, scavengers, and undoubtedly destroy a large quantity of harmful insects. When a flight of locusts invades the land they, together with the kites, render yeoman service to the husbandman. Even as a carcass attracts every vulture in the vicinity, so does a swarm of locusts bring together all the crows of the locality. They leave their ordinary occupations to dance attendance upon the devastating host, seizing the insects with their claws and conveying them to the beak in mid-air. Each crow devours locusts until threatened by death from a surfeit of food.

In a sense, crows and other omnivorous birds are more useful than the purely insectivorous ones. Like the careful housewife, they live upon whatever happens to be in season. If it be locusts, they have locusts for breakfast, locusts for lunch, locusts for dinner. They therefore form a highly efficient corps of reservists, ready at a moment's notice to wage war against insect invaders.

THE ROSY STARLING.

The rose-colored starling (*Pastor roseus*) spends the greater part of the year in India, although it does not breed there. This bird is said to commit "great depredations" in the cornfields, and, since it collects in immense flocks preparatory to migration, the charge is well founded. But we must not forget that the rosy starling feeds also on grass seeds, insects, and wild fruit, especially the mulberry, which grows without cultivation in India. In the United Provinces it is called the Mulberry bird on account of its fondness for that fruit. Chesney states that in Persia it is known as the "Locust bird." This name speaks for itself, and shows that the bird is by no means an unmixed evil. On the evidence at present available I do not think we are justified in setting down the rosy pastor as a foe to the husbandman. It should be added that many natives of India eat it.

FINCHES.

As regards the finches, we may neglect the amadavats (*Sporæginthus amandava*) and the other tiny species, which do not devour anything so large as a grain of corn. The weaver birds (*Ploceus baya*), however, eat wheat, and Messrs. Haagner and Ivy, I notice, state that the African species do damage to the crops. But it is my opinion that in India weaver birds subsist, by preference, on the seeds of the various species of tall grasses so common in that country. I do not know from observation on what they feed their young, but from the fact that they nest in the rainy season, I infer that the young are reared on insect food. It is therefore my belief that weaver birds ought to be numbered among the friends of the Indian husbandman. Their relatives, the yellow corn buntings, near relations of the English yellow-hammer, may prove to be his foes, since they do not breed in India. They visit Hindustan in large flocks in winter, and levy toll on the ripening corn, but they, like the weaver birds, appear to eat this only when grass seed is not available. Moreover, it is not improbable that they devour insects. Thus the case against them is "not proven."

The rose finch (*Carpodacus erythrinus*) is another winter visitor which feeds upon the grain crops, but it rarely occurs in sufficient numbers to do much damage, and, as is the case with its relatives, it seems more partial to the seeds of grass than to those of cultivated crops. Jerdon states that in South India he has observed it chiefly in bamboo jungle, feeding on the seeds of bamboos, whence the Telegu name—"bamboo-sparrow."

PAROQUETS.

The case against the beautiful green paroquets is, I fear, far stronger. "Pretty polly" appears never to touch insect food. There is no doubt that he is destructive to cereal crops in India. He has a bad habit of breaking off a head and casting it away after having eaten only one or two grains. He further does harm to fruit gardens. I have seen a rose-ringed paroquet (*Palæornis torquatus*) flying off with a small orange in his beak. If these birds were very abundant they would undoubtedly become serious pests. As it is they are kept well in check. Hundreds of thousands of these are caught as nestlings, and sold as pets for two annas apiece. The paroquet is the favorite cage bird in India; to have one in the house is considered lucky. Moreover, notwithstanding recent legislation, large numbers of green parrots' skins are exported from India by the plumage merchant. Thus man receives ample compensation for poor polly's larcenies.

PIGEONS.

Doves and pigeons, like parrots, never eat insects. Some species subsist almost exclusively on fruit, others on grain. The fruit-eating kinds do but little damage, since they feed mostly on wild figs and other fruit of no use to man. The various species of dove affect grooves and plantations of trees rather than cultivated fields, and I have never heard any complaints against them. The blue rock pigeons (*Columba intermedia*) devour food grains, but, as a set-off, they are good birds for the table. They appear to be less abundant in India now than formerly. Sportsmen keep down their numbers. I do not know of any place in India where pigeons are sufficiently numerous to do serious harm to the crops.

GEESE.

There remain the geese. These certainly do damage to the green shoots of the various grain crops, but are so useful as food, and afford so much pleasure to the sportsman that their annual influx into India must be regarded as an asset of considerable value. The same may be said of the common quail, which feeds chiefly on grain. Thus, of the 1,600 species of birds found in India we can count on our fingers all those which, on further inquiry, may prove to be foes of the farmer. The vast majority are his very good friends, and should be encouraged by every possible means.

EXPORT OF PLUMAGE.

In conclusion, a word on the exportation of plumage. As most people are aware, the government of India passed, nearly six years ago, a measure prohibiting the export of plumage, other than ostrich feathers, except as natural history specimens to museums. This act was not passed in haste. The question of the necessity for such legislation on account of the harm done to agriculture by the killing of useful birds for the sake of their plumage, was raised as long ago as 1869. It was not until 1887 that legislative action was taken. The enactment of 1887 not proving sufficiently efficacious, the more stringent act of 1903 was passed.

Thus the government of India has done all in its power for the birds and the agriculturists. Unfortunately, the export still continues, although, I believe, it has been considerably lessened. The law is evaded by the exporter making a false declaration as to the nature of his exports. I am glad to observe that a bill prohibiting the importation of such plumage into Great Britain is now before Parliament. This bill, if it becomes law, will render the Indian act far more effective.

Surgeon-General Bidie, in a pamphlet published eight years ago, gives a list of thirty-two birds which are, or were, captured in South India on account of their feathers. Some of these birds are to be numbered among the best friends of the Indian husbandman. But, inasmuch as the act of 1903 has come into force since Surgeon-General Bidie's paper was written, I do not propose to make it the basis of the remarks I am about to offer. A safer foundation is that afforded by the sales which have actually taken place in London of recent years. Large numbers of the following Indian birds have been sold in London since the passing of the act: Egrets, the "ospreys" of the feather trade, Impeyan or monal pheasants, paroquets, kingfishers, trogons, orioles, rollers, pittas, owls, jungle fowl and peafowl. With the solitary exception of the paroquets, these are all good friends of the Indian ryot. So that, notwithstanding recent legislation, the plume hunters are every year draining India of thousands of what Sir Charles Lawson well calls "a watchful and efficient bird police against multitudinous insect thieves." Thus, from a purely economic point of view, apart from the cruelty it involves, the trade in plumage birds is harmful to India.

EXTINCTION OF BIRDS.

There is also the question of the extinction of beautiful birds. Whether there is any danger of this I am not in a position to say, for my stay in India has not been sufficiently long for me to be able to form an opinion of the effect of this bird slaughter on the numbers of the various species. But Sir Charles Lawson, writing in 1900, states that "the continuous depredations, of a long series of years, have woefully reduced the means of supply (of birds' skins), as any one may notice for himself when he passes paddy fields, or strolls through silent, because birdless, plantations or forests." It is certainly significant that the beautiful Indian roller, or blue jay (*Coracias indica*) is a rare bird about both Madras and Bombay, while he becomes more plentiful as one goes inland. There seems to be no reason why this species should not thrive right up to the seashore, so that I am forced to attribute his scarcity on the coast near Bombay and Madras to the depredations of the plume hunter.

THE INDICTMENT AGAINST THE PLUME HUNTER.

There are three counts in the indictment against this individual. First, that he is causing to become extinct some of the most beautiful of God's creatures. Second, that he is robbing the husbandman of numbers of his most useful allies. Third, that he is guilty of much cruelty. As regards count number one, thanks to the action of the

Government, no Indian species, except possibly the monal pheasant (*Lophophorus refulgens*) seems in danger of early extinction. As to count number two, notwithstanding this legislation, the plume hunter continues to destroy birds useful to the cultivator. There remains the third count of the charge, that of cruelty. Upon this I would lay especial stress, for I am convinced that if ladies had even a faint idea of the cruelty which plume hunting involves, they would, with one accord, abstain from wearing any feathers save those of the ostrich and various game birds.

CRUELTY TO ANIMALS.

The low-caste inhabitants of India are, I regret to say, not, as a rule, characterized by kindness to animals. They seem quite unable to appreciate the fact that animals can feel. I have often observed donkeys staggering along so overloaded that at each step their hind legs "brushed," and blood issued from the places where the friction was greatest. I have seen, harnessed to a tonga, horses so exhausted that they could scarcely stand. On one occasion a friend and I walked a considerable portion of the journey from Rawalpindi to Murree in July because some of the tonga horses provided for us had not sufficient strength to pull the vehicle at more than a walking pace. On our way up we actually came upon the body of a horse that had dropped down and died from sheer exhaustion. We reported the matter to the local government, and suitable action was taken.

Some natives use what are known as "thorn bits," that is to say, bits provided with sharp spikes, so that when the reins are jerked these penetrate the flesh of the mouth of the unfortunate steed.

In India fowls are always sold alive at market. The cook, when he purchases a number of them, ties the legs of all tightly together, and, holding the tied-up bundle of legs, he carries the poor creatures home head downward.

When out shooting I find it necessary to examine every bird picked up to make sure that life is extinct, as otherwise the coolie that carries the "bag" will put living birds into the game stick, and there they will hang suspended by the neck until they die. Since animals are treated thus in everyday life, it is not pleasant to contemplate the kind of treatment meted out to his victims by the professional bird catcher—a low-caste man, brutalized by the constant butchery he perpetrates. He brings down his victim by means of a pellet of dried mud slung from a catapult, and wrapping the poor creature up in his loin cloth, leaves it to die a lingering death. As likely as not, the bird in question has a nest full of young ones. These starve to death. Even white men are guilty of similar cruelty. Colonel Ryan, in the

evidence which he gave, in June, before the select committee of the House of Lords on the importation of plumage prohibition bill, said:

> Last year I knew of another rookery (of egrets) in New South Wales where some brigands went down and destroyed, I think, about 50 birds. Shortly after it was done we sent a photographer up, who got a very interesting series of photographs taken. He photographed a lot of dead birds and some young ones that died in their nests, and he got one photograph, which is almost unique, of three young birds just with their heads dropping, almost at the point of death.

We have listened lately to much talk about the right of women to vote. I beg to point out that there are modes of exercising political power far more efficacious than an occasional visit to the polling station. Woman—voteless woman—can, if she will, do more than even the British Parliament to prevent the destruction of beautiful birds.

THE EVOLUTION OF THE ELEPHANT.[a]

[With 2 plates.]

By Richard S. Lull, Ph. D.

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Part I.

The modern word elephant, which may be used comprehensively to include all of the proboscidians, comes from the Greek ἐλέφας (ἐλέφαντ), a word first used in the literature by Herodotus, the father of history. The origin of the word is somewhat a matter of doubt, certain authorities deriving it from the Hebrew "eleph," an ox; others from the Hebrew "ibāh," Sanskrit "ibhas," an elephant, comparing this with the Latin "ebur," meaning ivory. Another Sanskrit word is "hastīn," elephant, from "hasta," a hand or trunk. Thus the ancients emphasized the three characteristics of the proboscidians, size, the tusks, and the trunk, which are the most striking features of the most remarkable of beasts.

The proboscidians may be defined as large, trunk-bearing mammals, with pillar-like limbs, short neck and huge head, often with protruding ivory tusks, the modified upper and, in earlier, extinct types, the lower incisor teeth. The proboscidians constitute a suborder of the great group of ungulates or hoofed mammals, yet have their nearest living allies in creatures strangely remote in size, form, and environment from the lordly elephant, for the paleontologist, in his ardent search for family trees other than his own, often discloses some seemingly paradoxical relationships which completely upset the older ideas of classification. Explorations have recently brought to light evidence to show that the sea-living Sirenia, whose American representative is the Florida manatee, can claim close relationship with the elephants, though nothing could be more unlike than the proboscidians and the fish-like Sirenia with broad swimming tail, front limbs reduced to flippers, and no hind limbs at all.

[a] Reprinted by permission, after author's revision, from the American Journal of Science, Vol. XXV, March, 1908.

On the other hand, anatomists had already recognized certain similarities of structure between the elephants and the *Hyracoidea*, the Hyraces, or conies, furry, rabbit-like animals not more than 18 inches in length, short ears, tailless, and with hoof-like nails instead of the claws one would be led to expect from their general appearance. They are confined to Africa with the exception of the Syrian conies, which the Book of Proverbs tells us "are but a feeble folk, yet make their houses in the rocks." Recent exploration in Egypt has revealed the presence of a hyrax much larger than the modern representatives of the order, and proclaiming by its structure a much closer approximation with the early elephants whose bones are found entombed in the same deposits.

FIG. 1.—The Manatee, *Manatus australis;* after Brehm.

Elephants show a curious intermingling of primitive and specialized characters, for in spite of the remarkable development of teeth, tusks, and trunk, many of the other bodily features would serve to place them among the most archaic of the ungulates.

The primitive features of the elephants, briefly enumerated, are as follows: Simplicity of stomach, liver, and lungs, and the rather low type of brain. The limbs combine the archaic features of five toes in front and rear and a serial arrangement of wrist and ankle bones with the admirable adaptation of the entire limb to the support of the huge body. The limbs are further primitive in the retention of both bones of the lower leg and arm, for in most other ungulates one of these in each member becomes greatly reduced, being, for part of the length at least, often entirely absent.

The special adaptations are, as in the horses, primarily for food-getting and locomotion, although incidentally the elephants have developed admirable weapons for defense, which, together with the great size and thick skin, render them almost impregnable to their enemies of the brute creation.

ADAPTATIONS OF THE LIMBS AND FEET.

The development of the pillar-like limb of the elephant has been shown to be merely a device to support the enormous bodily weight and was independently acquired in other groups of land animals

FIG. 2.—Conies, *Hyrax abyssinicus;* after Brehm.

of huge size. In most quadrupeds, however, the knee and elbow are permanently bent, the upper limb bones being of the shape of an elongated S. Increasing weight necessitates a straightening of the limb in order that the weight may be transmitted through a vertical shaft. This is more far-reaching than one would suppose, as it implies also a straightening of the bones themselves and a shifting of the articular facets from an oblique to a right angle with reference to the long axis of the bone. The foot has changed its posture from the primitive plantigrade position, for the heel and wrist bones are elevated above the ground and a thick pad of gristle has developed beneath them in each foot, forming a cushion to receive a share of

the weight. The toes are not separate, but are embedded in the common mass of the cylindrical foot, the hoofs being represented by nails around its forward margin. These may be fewer in number than the toes.

ADAPTATIONS OF THE SKULL AND TEETH.

Owing to the shortness of the neck and the height of the head from the ground, the proboscis or trunk, which is merely an elongation of the combined nose and upper lip, becomes a most necessary device for securing food and water. This organ is composed of a great number of muscles, and so combined and controlled as to give not only enormous strength but the utmost delicacy of movement. The trunk terminates in one (Indian) or two (African elephant) finger-like projections, with which a pin can be picked up from the ground, while the entire organ has sufficient strength to uproot a tree.

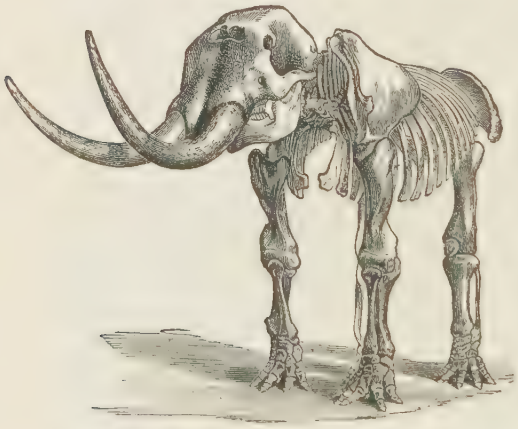


FIG. 3. American mastodon; after Owen.

The development of the trunk has been accompanied by a marked change in the character and form of the skull, which is merely a mechanical adaptation to provide the leverage necessary to wield so weighty an organ. This has been brought about by a shortening of the skull, accompanied by a corresponding increase in height. The result is that the base of the trunk has been brought much nearer the fulcrum at the neck, thus shortening the weight arm of the lever, while the increasing height not only lengthens the power arm, but gives more surface for the attachment of muscles and the great elastic ligamentum nuchæ which aids in supporting the head.

This change in the form of the skull, while it gives to the physiognomy of the animal that dignified, intellectual look, does not imply a similar development of the brain, for the brain case has increased but little, the great size of the skull being largely due to the development of air cells in the cranial bones, so that the actual thickness of the roof of the skull is greater than the height of the brain chamber itself, a feature well shown in figure 4.

The teeth.

It is generally true among mammals that the normal number of teeth in the adult is 44, 11 in each half of each jaw. This number is rarely exceeded, but often because of specialization a reduction in numbers occurs until, as in the ant-bears, the limit of a totally toothless condition may be reached. The elephants, owing to the great increase in the size of the individual grinders and the loss of all but two upper incisors in the forward part of the mouth, have the total number of teeth reduced *apparently* to six, as but one fully formed grinder is in use in each half of each jaw at any one time.

Actually, however, the number of teeth is greater than this, owing to the peculiar manner of tooth succession, in which, instead of having the adult teeth replace those of the milk set vertically, the succession is from behind forward. The tooth forms in the rear of each jaw and moves forward through the arc of a circle (see fig. 4), gradually replacing the preceding tooth as it wears away through use, until the final remnant is crowded from the jaw and the new tooth is in full service. Bearing this in mind, it is evident that the full tooth series is not confined to those present at any one time, but should include not only teeth which have gone before, but, in a young animal, those yet to come. Sir Richard Owen gives the total dentition of the modern elephant as follows: Incisors $\frac{2-2}{0-0}$, molars $\frac{6-6}{6-6}=28$, which, being interpreted, means that there are in each half of the upper jaw two tusks, the first milk tusk being succeeded by the permanent one, while in the lower jaw there are none. There are all told six grinders in each half of each jaw, the first appearing at the age of 2 weeks and being shed at the age of 2 years. The second is shed at the age of 6, the

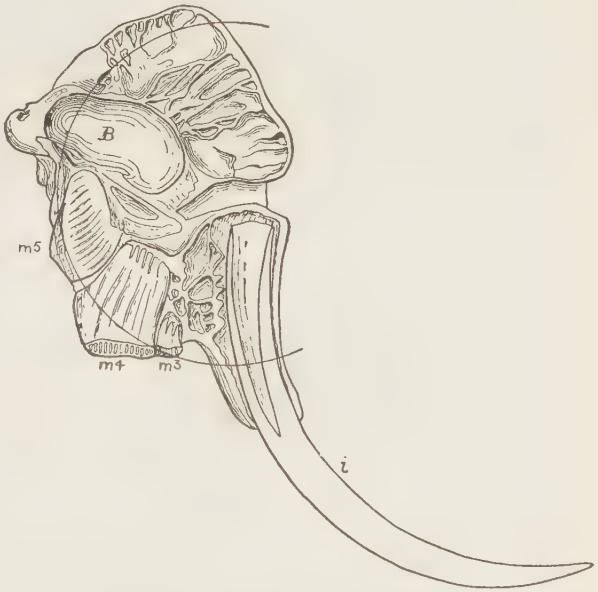


FIG. 4.—Sectioned skull of Indian elephant; after Owen.

third at 9, the fourth from 20 to 25, the fifth at 60, while the sixth lasts for the remainder of the creature's life, up to the age of 100 to 120 years.

The structure of a single tooth finds no exact parallel among other mammals, as it consists of a series of vertically placed transverse plates, each composed of a flattened mass of dentine or ivory surrounded by a layer of enamel. The plates are in turn bound together into a solid mass by a third material known as cement. When the upper surface of the tooth becomes worn through use, the hard enamel appears as a series of narrow transverse ridges between which lie the dentine and cement in alternate spaces, as two enamel ridges with the inclosed dentine are derived from each plate. In order to keep the teeth in proper condition, a certain amount of harsh, siliceous grasses or woody material is necessary; otherwise the teeth become as smooth as polished marble, and as the rate of growth is nicely adjusted to normal wear the elephant suffers greatly when given improper food. The number of plates in the largest teeth varies from 10 to 11 in the African elephant to 27 in the Indian. The hairy mammoth had the most numerous and finest plates of all, representing in this respect the culmination of evolution.

5a.

5b.

FIG. 5.—Crown view and section of a molar tooth, original.

The tusks are merely modified incisor teeth of the upper jaw which continue to grow throughout life. They are composed entirely of dentine or ivory of a superlative quality, the enamel being reduced to a small patch at the tip, which soon becomes worn away. The tusks have various uses, but their primitive purpose is for digging. The African elephant is so industrious a digger that the right tusk is always the shorter, as it has to bear the brunt of the work. Tusks are so small as to be apparently absent in the female Indian elephant and often in the male, while they are present in both sexes in

the African species. In size they are always much smaller in the Indian form, as 76 pounds is the maximum weight for a single tusk, while the greatest recorded size of those of the African elephant is 10 feet ¾ inch in length by 23 inches in circumference at the base, with a weight of 224 pounds for the right tusk, while the left measured 10 feet 3½ inches in length by 24½ inches in circumference and weighed 239 pounds, a total of 463 pounds for the pair.

MENTALITY.

In spite of its archaic type the brain is large and the surface is highly convoluted, the weight being on the average 8½ pounds—more than double that of man. The intelligence of the elephant has been exaggerated by some writers and greatly minimized by others. Sir Henry Baker, a British explorer, and the German naturalist Schillings give us the most unbiased view of the mentality of the elephant. Elephants possess a remarkable memory of injuries, real or fancied, of misfortunes, and of the time and place of the ripening of favorite fruits. They also learn to perform complex labors, as the carrying and piling of logs in the teak yards in India, without other directions than the initial order. They are said to be weather-wise and to be able to foretell rain some days in advance. Elephants are obedient and docile, notably those of India, but the males especially are subject to periods of nervous excitement, apparently of a sexual nature, known as "must," when they become very dangerous and sometimes destroy the keepers in their paroxysms of rage. Ultimately all male elephants become surly and intractable. In the wild state such are known as rogues, and live apart from their kind until they die. A fine specimen of the Indian elephant, known as "Chunee," was brought to England in 1810. He was very tractable and continued to grow until 1820, when the first paroxysm occurred, in which he attempted to kill his keeper. Similar paroxysms occurred with increasing force until 1826, when the violence of the animal necessitated its slaughter. With Chunee this condition occurred very early in life, as the animal was not fully adult at the time of its death. The famous Jumbo, an African elephant, was sold from the London Zoological Gardens because he was no longer trustworthy, from the same cause. He was not, however, a confirmed rogue even when he died, three and a half years later. Jumbo was about 25 years old at the time of his death.

There is a possible parallelism between human mental development and that of the elephant. One of the most potent factors in the evolution of man's mind is his ability to handle various objects and thus bring them before the face for examination. This is also found in the elephant, although to a less extent, and undoubtedly has aided materially in its mental development as well.

Elephants are rightly accused of timidity and cowardice, though when brought to bay rage may simulate courage, making a charging tusker a most formidable foe. In common with most forest and jungle dwellers, elephants, while relatively dull of sight, are keen of scent and hearing, in fact marvelously so, for, as Schillings tells us, they either have an acuteness of some known sense far beyond our comprehension or possibly some other sense unknown to us. The sentinels of the herd stand with uplifted trunk, which emphasizes the value of the sense of smell.

Elephants rarely breed in captivity, almost all of the tamed individuals having been born wild; hence artificial selective breeding, which has given rise to such valuable results in the betterment of domestic animals, is unavailable for the improvement of the race.

The rate of increase is extremely slow, for Darwin tells us that they begin to bear young at 30 years and continue to do so until 90, during which time six single young are produced on the average. But to illustrate the necessity of a check upon increase among animals, Darwin says that even at this slow rate the offspring of a single pair would in five hundred years amount to 15,000,000, provided they all lived to maturity.

EVIDENCES OF EVOLUTION.

The evidences of evolution are threefold: Structure, as shown by comparative anatomy, ontogeny, or individual development, and phylogeny or racial history. The last, paleontology makes known to us. We may, by comparing the structure of a given form with that of other animals, gain an insight into the probable course of modifications which it has undergone in the development of its distinctive features and often a hint, at least, as to its ancestry and relationship, as in the case already mentioned of the Hyracoidea and elephants. Again, the small hind limb and hip bones buried deep within the body of the whales and the hip bones alone in the case of the manatee (Sirenia), having no possible function, are indubitable evidence for descent in each case from some land-dwelling quadrupedal type. This has been corroborated in the last instance by the recent finding, in the Eocene of the Egyptian Fayûm, of Sirenia *with* hind limbs.

Ontogeny.

Embryology shows us the curious parallelism which exists between the individual's history and that of the race, that of the individual being in most cases a more or less abridged summary of that of its ancestors.

I have spoken of the shortening and corresponding increase in height of the elephant's skull to provide the leverage necessary in

wielding the huge trunk. The development of this feature is beautifully shown in individual growth, for the new-born elephant has a relatively long, low skull, the walls of which are slightly thickened, so that the brain chamber fills the skull completely as in most other mammals. During the course of growth, however, the skull walls thicken greatly through the development of the air cells, while the brain cavity increases comparatively little, just as one would predict from the structure of the adult skull.

Of the prenatal life of the elephant, covering a period of twenty months, we know very little, but it is reasonable to suppose that embryology would give us much more light upon the development of elephantine features. New-born young are elephant-like in every particular with the exception of the skull.

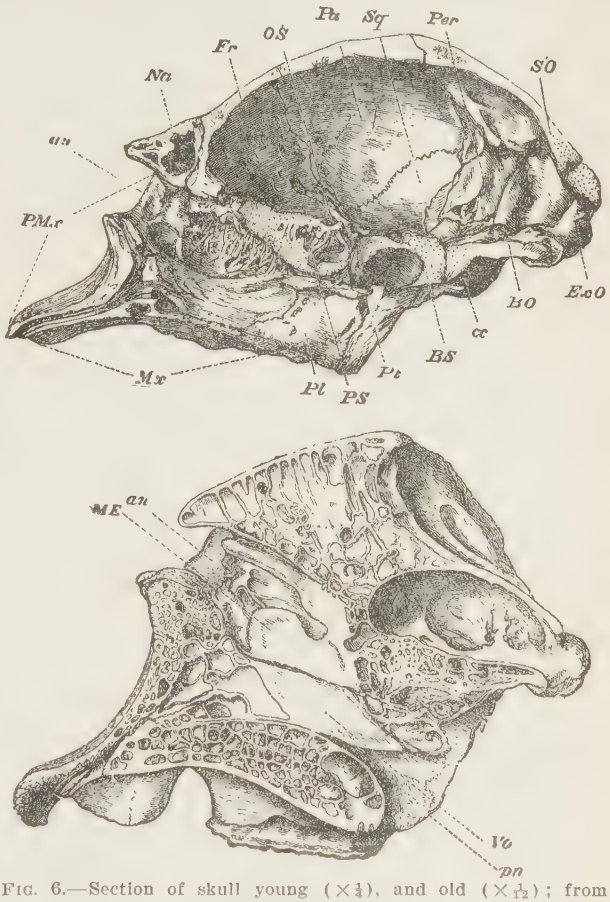


FIG. 6.—Section of skull young ($\times \frac{1}{4}$), and old ($\times \frac{1}{12}$); from Flower's Osteology.

Paleontology.

The great proof of the evolution of a race of animals is the finding in the ancient rocks more and more primitive forms as one recedes in time, until the most archaic type is reached. By the study of such a series of fossils not only may the evolutionary changes be learned, but former geographical distributions, the original home, and the various migrations of the race. While this matter is treated much more fully in the second and third parts of this paper, a brief summary of the racial history may be given as follows:

The earliest known proboscidians were discovered in the Egyptian Fayûm, in beds of middle Eocene age. Their remains are also found in the upper Eocene of the Fayûm, but the Oligocene elephants are as yet undiscovered. During the early Miocene the first migration occurred into Europe and thence to the region of India and even as far as North America, both of which were reached by the middle Miocene. The Pliocene saw the elephants in their millenium, having reached the widest dispersal and the maximum in numbers of species. During Pleistocene times the Proboscidia covered all of the great land masses except Australia, but were diminishing in numbers, and toward the close of the Pleistocene the period of decadence began, resulting in the extinction of all but the Indian and African elephants of to-day.

SUMMARY OF THE EVOLUTION.

The physical changes undergone by the race are also clearly shown, as the paleontological series is very complete. These changes may thus be summarized: Increase in size and in the development of pillar-like limbs to support the enormous weight. Increase in size and complexity of the teeth and their consequent diminution in numbers and the development of the peculiar method of tooth succession. The loss of the canines and of all of the incisor teeth except the second pair in the upper and lower jaws and the development of these as tusks. The gradual elongation of the symphysis or union of the lower jaws to strengthen and support the lower tusks while digging, culminating in *Tetrabelodon angustidens*. The apparently sudden shortening of this symphysis following the loss of the lower tusks and the compensating increase in size and the change in curvature of those of the upper jaw.

The increase in bulk and height, together with the shortening of the neck necessitated by the increasing weight of the head with its great battery of tusks, necessitated the development of a prehensile upper lip which gradually evolved into a proboscis for food-gathering. The elongation of the lower jaw implies a similar elongation of this proboscis in order that the latter may reach beyond the tusks. The trunk did not, however, reach maximum utility until the shortening jaw, removing the support from beneath, left it pendant, as in the living elephant.

The change in the form of the skull developed pari passu with the growth of the tusks and trunk, as it is merely a mechanical adaptation to give greater leverage in the wielding of these organs. It may readily be seen that these changes curiously interact upon one another; the result of the evolution of its parts being the development of a most marvelous whole.

FIG. 7.—Evolutionary changes of Proboscidia. Based upon restorations modeled by R. S. Lull. a, *Elephas columbi;* b, *Mammut americanum;* c, *Tetrabelodon angustidens;* d, Palæomastodon; e, Mœritherium.

ELEPHANTS CONTEMPORARY WITH MAN.

Aside from the species of elephant now living, at least three extinct types were coeval with mankind, one distinctly American, the mastodon, *Mammut americanum*, one confined to Europe and Southern Asia, *Elephas antiquus*, while the third, the hairy mammoth, *Elephas primigenius*, was common to both, and to northern Asia as well. Of these the mammoth is without exception the best known of all prehistoric animals, for not only have its bones and teeth been found in immense numbers, but, in several instances, frozen carcasses have been discovered nearly or quite intact, the hair, hide, and even the viscera and muscles wonderfully preserved. In many instances these were irrevocably lost or were devoured by the dogs and wolves or by the natives themselves. Two specimens have been preserved, however, and are now in the St. Petersburg Zoological Museum.

Of these one was found in the Lena Delta in Siberia, in 1799, and secured in 1806. The skeleton with patches of hide adhering to the head and feet may still be seen, but the flesh of the animal was devoured by wolves and bears after being preserved in nature's cold-storage warehouse for thousands of years (pl. 1). In 1901 another specimen was found at Beresovka, Siberia, 800 miles west of Bering Strait and 60 miles within the Arctic Circle. It is supposed that this creature slipped into a crevasse in the ice which may have been covered by vegetation, as in the Malaspina Glacier of Alaska. That the poor brute died a violent death is certain from the fracture of the hip and one foreleg and the presence of unswallowed grass between the teeth and upon the tongue. A great mass of clotted blood in the chest tells how suddenly the Reaper overtook it, the creature having burst a blood vessel in its frantic efforts to extricate itself. Much of the hair had been destroyed when the animal was dug out of the cliff, but the collector, M. O. F. Herz, has preserved a very accurate record of texture and color of the hair on different parts of the body. This consists of a woolly undercoat, yellowish-brown in color, and an outer bristly coat varying from fawn to dark brown and black. The hair on the chin and breast must have been at least half a yard in length, and it was also long on the shoulders; that of the back, however, was not preserved.

This interesting relic is mounted in the St. Petersburg Museum, the skin in the attitude in which it was found, while the skeleton is in walking posture beside it (pl. 2).

Immense quantities of fossil ivory have been exported from Siberia, there having been sold in the London market as many as 1,635 mammoth tusks in a single year, averaging 150 pounds in weight; of these but 14 per cent were of the best quality, 17 per cent inferior, while more than half were useless commercially. The total number of

MAMMOTH FOUND FROZEN IN THE ICE NEAR BERESOVKA, SIBERIA, AS IT LAY IN THE CLIFF.

After Herz.

MAMMOTH OF BERESOVKA MOUNTED IN THE ST. PETERSBURG MUSEUM.
After Herz.

mammoths represented by the output of fossil ivory since the conquest of Siberia is not far from 40,000, not, of course, a single herd, but the accumulations of thousands of years. The oyster trawlers from the single village of Happisburg dredged from the Dogger Banks off the coast of Norfolk, England, 2,000 molar teeth, besides tusks and other mammoth remains, between the years 1820 and 1833. This indicates not only the great profusion of the mammoths of the Pleistocene, but the existence of comparatively recent land connection between England and the continent.

Direct evidences of the association of man and the mammoth are plentiful in Europe but strangely enough absolutely wanting in North America, although we have every reason to believe that such an association existed in the New World as well as in the Old. In Europe not only have the bones of man and the mammoth been found intermingled in a way that implied strict contemporaneity, but still more striking evidence is shown in the works of prehistoric artists. The fidelity with which the mammoth is drawn indicates that the artist must have seen the animal alive.

Fig. 8.—Charging mammoth; after Lubbock.

One of the most notable of these relics is an engraving of a charging mammoth drawn upon a fragment of mammoth tusk found in a cave dwelling at La Madeline in southern France. In the Grotte des Combarelles (Dordogne), France, there are in addition to some forty drawings of the horse at least fourteen of the mammoth. These are mural paintings or engravings, the former being executed in a black pigment and some kind of a red ocher, while the latter are scratched or deeply incised, sometimes embellished with a dark coloring matter (oxide of manganese). It is especially interesting to note that the people of that day were not only sufficiently advanced to have artists of a very high order, but that they also had begun to domesticate the horse, if one may judge from the indications of harness on some of the equine figures. The horse is a most potent factor in the civilization of mankind.

In the caverns of Fond de Gaume in southern France there are at least 80 pictures, largely those of reindeer, but including two of the mammoth. The actual association of man and the mammoth in America has not been proven. In Afton, Oklahoma, is a sulphur spring from which have been brought to light remains of the mam-

moth (*Elephas primigenius*) and mastodon (*Mammut americanum*) and numerous other animal remains, such as the bison and prehistoric horses. In the spring there were also found numerous implements of flint, mainly arrowheads. This naturally was first interpreted as an instance of actual association of mankind and the elephants, but careful investigation proved that the elephant remains far antedated the human relics, and that the latter were votive offerings cast into the spring by recent Indians as a sacrifice to the spirit occupant, the bones being venerated as those of their ancestors (Holmes). Another instance, not of the association of the mammoth with mankind, but of the mastodon, is probably authentic. This was in Attica, New York, and is reported by Prof. J. M. Clarke. Four feet below

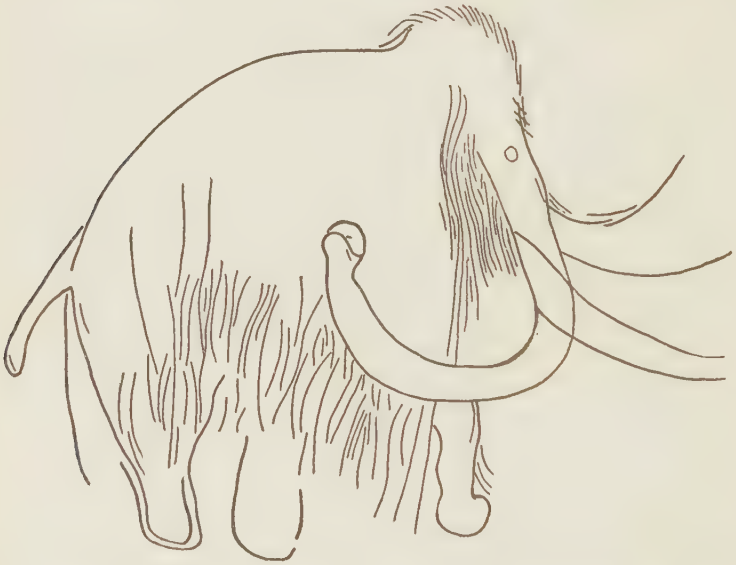


FIG. 9.—Prehistoric engraving of mammoth on wall at Combarelles; after MacCurdy. One-sixth natural size.

the surface of the ground, in a black muck, he found the bones of the mastodon, and 12 inches below this, in undisturbed clay, pieces of pottery and 30 fragments of charcoal (Wright). The remains of the mastodons and mammoths are very abundant in places, the Oklahoma spring already mentioned producing 100 mastodon and 20 mammoth teeth, while the famous Big Bone Lick in Kentucky has produced the remains of an equal number of fossil mastodons and elephants.

Indian tradition points but vaguely to the proboscidians, and one can not be sure that they are the creatures referred to, yet it would be strange if such keen observers of nature as the American aborigines should not have some tales of the mammoth and mastodon if their forefathers had seen them alive. One tradition of the Shawnee

Indians seems to allude to the mastodon, especially as its teeth led the earlier observers to suppose that it was a devourer of flesh. Albert Koch, in a small pamphlet on the Missourium (mastodon) discovered by him in Osage County, Missouri, and published in 1843, gives the tradition as follows:

Ten thousand moons ago, when nothing but gloomy forests covered this land of the sleeping sun—long before the pale man, with thunder and fire at his command, rushed on the wings of the wind to ruin this garden of nature—a race of animals were in being, huge as the frowning precipice, cruel as the bloody panther, swift as the descending eagle, and terrible as the angel of night. The pine crushed beneath their feet and the lakes shrunk when they slaked their thirst; the forceful javelin in vain was hurled, and the barbed arrows fell harmlessly from their sides. Forests were laid waste at a meal and villages inhabited by man were destroyed in a moment. The cry of universal distress reached even to the regions of peace in the West; when the Good Spirit intervened to save the unhappy; his forked lightnings gleamed all around, while the loudest thunder rocked the globe; the bolts of Heaven were hurled on the cruel destroyers alone, and the mountains echoed with the bellowings of death; all were killed except one male, the fiercest of the race, and him even the artillery of the skies assailed in vain; he mounts the bluest summit that shades the sources of the Monongahela, and, roaring aloud, bids defiance to every vengeance; the red lightning that scorched the lofty fir and rived the knotty oak glanced only on this enraged monster, till at length, maddened with fury, he leaps over the waves of the West, and there reigns an uncontrolled monarch in the wilderness, in spite of Omnipotence.

Part II.

THE EARLY PROBOSCIDIANS.

Mœritherium.

The earliest known genus of proboscidians is *Mœritherium*, a small, tapir-like form, from the Middle Eocene Qasr-el-Sagha beds of the Fayûm in Egypt. This creature was probably a dweller in swamps, living upon the succulent, semiaquatic herbage of that time. It has little that suggests the elephants of later days and, were it not for transitional forms, would hardly be recognized as a proboscidian at all. However, one can see the beginnings of distinctively elephantine features. The hinder part of the cranium is already beginning to develop the air cells or diploë, the nostril opening and nasal bones are commencing to recede, indicating the presence of a prehensile upper lip, and the reduction of the teeth has begun, the second pair of incisors in each jaw being already developed as tusks.

FIG. 10.—*Mœritherium* skull; after Andrews (× ⅓).

Those of the upper jaw were dagger-like and downwardly projecting, while the lower ones were directed forward, their combined upper surface forming a continuation of the spout-like union or symphysis of the jaws. The molar teeth, 24 in number, bore on the crown four low tubercles partially united into two transverse crests. The neck was of sufficient length to enable the animal readily to reach the ground, though the prehensile lip must have been used for food-gathering. Our knowledge of the creature's bodily form is imperfect, as a complete skeleton has not been found. *Mœritherium* measured about 3½ feet in height, and existed up into the Upper Eocene as a contemporary of *Palæomastodon*, doubtless owing to a continuation of those favorable conditions under which it lived.

FIG. 11.—Tooth of *Mœritherium* (× ½).

Palæomastodon.

Palæomastodon of the Upper Eocene was more elephant-like than its predecessor, *Mœritherium*, and of larger size, while its limbs were much like those of more modern types. The skull has increased materially in height, with a considerable development of air cells in the bones. The small nasals with the nasal openings had receded so that they lay just in front of the orbits, much as in the tapir of to-day. This would imply the development of a short extensile proboscis, essentially like that of the modern elephant except for size. The upper and lower canines and incisors have entirely disappeared, except the second paid of incisors in each jaw, which have become well-developed tusks. Those of the upper jaw are large, downwardly curved, and with a band of enamel on the outer face. The lower jaw has elongated considerably, especially at the symphysis, and the lower tusks point directly forward as in *Mœritherium*. The proboscis possibly did not extend beyond the lower tusks while at rest, though it could probably be extended beyond them. The premolar teeth have two while the molars have three transverse crests composed of distinct tubercles, and the cingulum of the hindermost tooth shows

FIG. 12.—Skull of *Palæomastodon* (× 1/12); after Andrews.

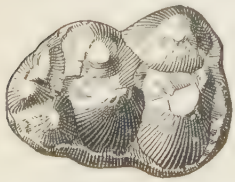


FIG. 13.—Tooth of *Palæomastodon* (× ½).

a strong tendency to form yet another crest. There were 26 teeth altogether. The neck is still fairly long, though the hinder neck vertebræ are beginning to shorten.

Palæomastodon is confined to the Upper Eocene, and has thus far been found only in the Fayûm region.

CLASSIFICATION OF THE LATER PROBOSCIDEA.

We know as yet no Oligocene proboscidians, the next forms being found in the lower Miocene of northern Africa and Europe, so that a considerable break occurs in the continuity of our series. It is evident that the line was still African in distribution, for apparently the exodus from Egypt did not occur before Miocene times.

The mastodons have been divided in two ways, one depending upon the number of ridges borne upon the grinders, while the other classification is based upon the number and character of the tusks. The latter seems the more logical from a developmental viewpoint. The first of these genera is *Tetrabelodon*, with four enamel-banded tusks. The second is *Dibelodon*, having but two tusks which still retain the band of enamel. The last genus is *Mammut*, with enameless upper tusks in the adult, though one or two may also be present in the adolescent lower jaw. The latter are sometimes retained throughout life.

Tetrabelodon.

The third recorded stage in the evolution of the elephants is represented by the Miocene *Tetrabelodon angustidens*, of which a splendid specimen from Gers, France, is preserved in the museum of the Jardin des Plantes at Paris. It was an animal of considerable size, nearly as large as the Indian elephant, but differing markedly from the latter in the peculiar character of the lower jaw, which was enormously long at the symphysis and contained a pair of relatively short tusks. This form represents the culmination of the jaw elongation, for in its successors the symphysis is rapidly shortened and the inferior tusks finally disappear. The upper tusks in *Tetrabelodon* were longer than those of the lower jaw, but did not extend much beyond the latter. The tusks had an enamel band upon the outer and lower face and were slightly curved downward. The nasal orifice had receded farther to the rear, indicating a still greater development of the trunk than in *Palæo-*

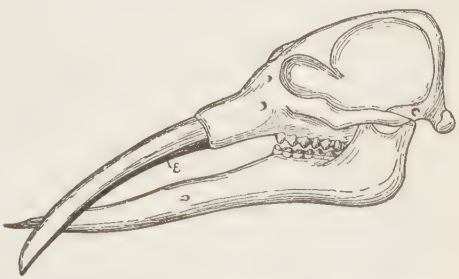


FIG. 14.—Skull of *Tetrabelodon angustidens.*

mastodon. The proboscis, still supported from beneath by the rigid lower jaws, could only be raised and moved from side to side. The neck is now quite short, so much so that were it not for the proboscis and tusks this creature could not reach the ground. Both upper and lower tusks show signs of wear which could only be caused by digging, those on one side being often much more worn than on the other.

The teeth have increased in size to such an extent that but two adult grinders at a time can be contained in each half of the jaws.

FIG. 15.—Tooth of *Tetrabelodon angustidens* (×¼).

Tetrabelodon was a widely spread, migratory form, for we find species referable to this genus not only in Europe but in Africa, Asia, and in North America. In Eurasia it gave rise to *Mammut* through the loss of the lower tusks and the enamel band, while in America there arose *Dibelodon*, which retained the enamel band and which was the first proboscidian to reach South America after the formation of the Central American land connection either late in the Miocene or in the early Pliocene.

Dibelodon.

The genus *Dibelodon* is known principally from the jaws, teeth, and tusks, though two splendid skulls of *D. andium* are preserved in the Museo Nacional in Buenos Aires. The upper tusks are well developed, displaying an elongated spiral form, with a well-devel-

FIG. 16.—Skull of *Dibelodon andium*.

oped enamel band, but the lower jaw is quite short, though the symphysis is longer and more trough-like than in the genera *Mammut* and *Elephas*. The lower tusks have entirely disappeared, and with the shortening of the jaw the trunk must have become pendant, as in the modern elephants.

The genus *Dibelodon* contains several species, among which are *Dibelodon humboldtii* (Cuvier), *D. mirificium* (Leidy), *D. præcursor* (Cope), and *D. andium* (Cuvier). Of these *Dibelodon humboldtii* and *D. andium* ranged into South America and were, in fact, almost

the only proboscidians to cross into the southern hemisphere of the New World. Some of these animals lived in the high Andes at an elevation of 12,350 feet above the level of the sea at a time when the region had a greater rainfall than now and therefore a richer vegetation.

Mammut.

This genus reaches its culmination in the American mastodon, a creature of great bulk, though about the height of the Indian elephant. It was, however, much more robust, a feature especially noticeable in the immense breadth of the pelvis and the massiveness of the limb bones. The feet were more spreading than in the true elephants, which, together with the character of the teeth and the conditions under which the remains are found, points to different habits of life from those of the mammoth, the mastodons being more distinctively forest-dwelling types. The skull differs from that of the true elephants in its lower, more primitive contour, for while there is a large development of air cells in the cranial walls the brain cavity is relatively larger. The tusks are well-developed, powerful weapons, not so sharply curved as in the elephants, though in this respect individuals vary. The tusks are very heavy at the base and taper rapidly, curving inward at the tips. In the lower jaw the tusks are vestigial, being apparently present only in the male. Usually they are soon shed, and the sockets may entirely disappear, as in the Otisville mastodon at Yale, whereas the Warren mastodon now in the American Museum, a fully adult animal, retained the left lower tusk, which is about 11 inches in length. The socket of the right tusk is also still distinct.

FIG. 17.—Skull of the American mastodon.

FIG. 18.—Tooth of mastodon (× ¼).

The grinding teeth were of large size, two in each half of either jaw, as in the *Tetrabelodon*, but the crests are simpler with but few accessory cusps. The crown of the tooth is covered with thick enamel, which in turn is overlain by a thin layer of cement before it cuts the gum. This is soon removed by wear. These teeth are admirably adapted for crushing succulent herbage such as leaves and tender twigs and shoots, but not for grinding the siliceous grasses which form a necessary part of the food of the true elephants. "Broken

pieces of branches varying from slender twigs to boughs half an inch long" have been found within the ribs of a mastodon together with "more finely divided vegetable matter, like comminuted twigs to the amount of four to six bushels." "Twigs of the existing conifer *Thuia occidentalis* were identified in the stomach of the New Jersey mastodon, while that of Newburg, New York, contained the boughs of some conifer, spruce or fir, also other not coniferous, decomposed wood. A newspaper account of the finding of the great Otisville mastodon, recently mounted at Yale, says that the region of the stomach contained "fresh-looking, very large leaves, of odd form, and blades of strange grass of extreme length and 1 inch to 3 inches in width."

TRUE ELEPHANTS.

In order to trace the evolution of the true elephants we must go back once more to the Upper Miocene of southern India to the form known as *Mammut latidens*. This creature gave rise to a species variously known as *Mastodon elephantoides* or *Stegodon clifti*, for its transitional character is such that authorities differ as to whether it is a mastodon or an elephant.

Stegodon.

In *Stegodon* the molar teeth have more numerous ridges than in the true mastodons, and the name *Stegodon* is given because of the roof-like character of these ridges, the summits of which are subdivided into five or six small, rounded prominences. There is a thin layer of cement over the enamel in an unworn tooth, but no great accumulation in the intervening valleys as in the elephants. These teeth show how slight the transition is, however, merely a filling of cement to bind the crests together and the elephant tooth is formed.

Stegodon embraces at least three species, the home of which was central and southern India, though two of them ranged east as far as Japan, then united to the Asiatic continent. *Stegodon insignis* lived into Pliocene times. True elephants, derived from the Stegodonts, existed in India, their remains being found in the Siwalik hills.

During Pliocene times there existed in Europe two immense elephants, known as *Elephas meridionalis* and *E. antiquus*, each of which lingered on into the cooling climate of the Pleistocene. The former, while ranging as far north as England, was more southerly in general distribution and of a size which has probably never been exceeded except possibly by *Elephas imperator* of North America. A mounted specimen of *Elephas meridionalis* in the Natural History Museum of the Jardin des Plantes at Paris, France, measures 13 feet and 1 inch at the shoulder, and probably exceeded this in the flesh. The tusks

are massive, but do not reach the extreme of development of the later mammoths, while the teeth have rather coarse lamellæ.

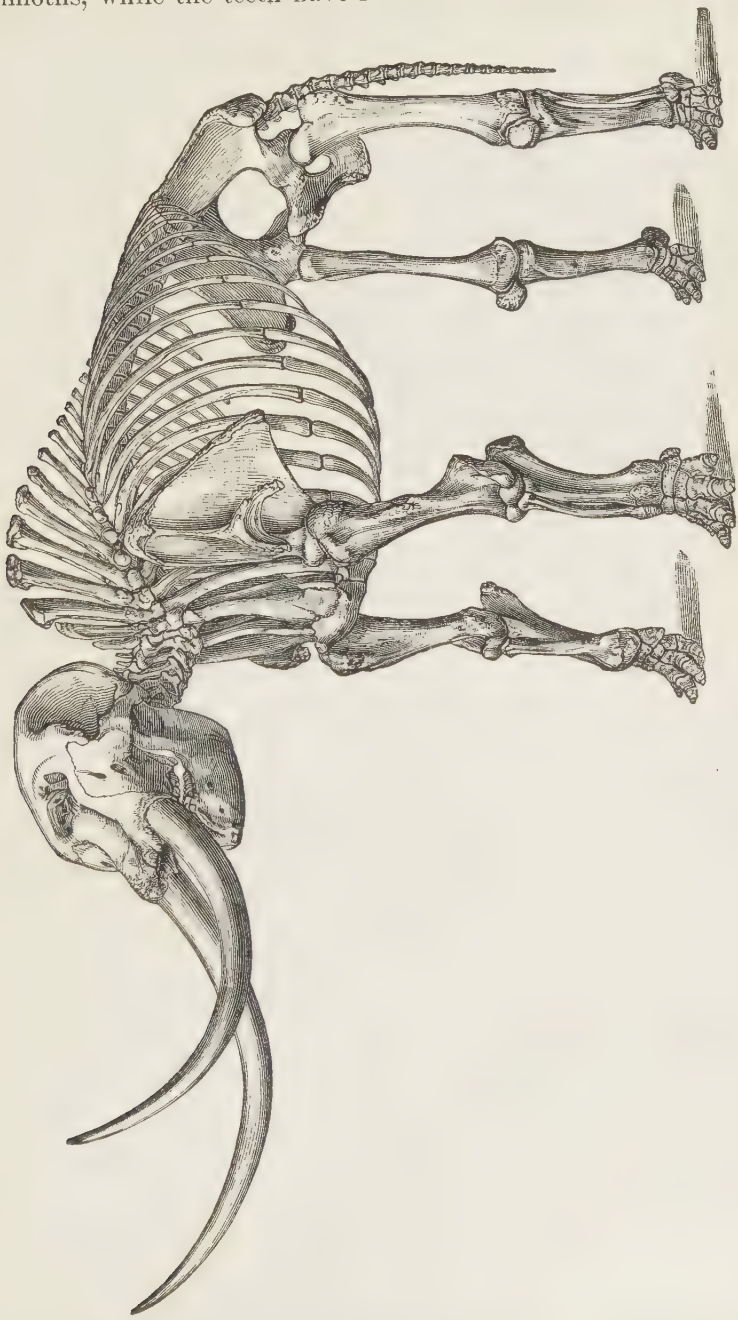


Fig. 19.—Marsh's restoration of the Otisville mastodon now mounted in the Yale Museum.

Elephas antiquus stands midway in character between the African and Indian elephants of to-day. The tusks were nearly straight, and

the creature was also of great size. It is first found in the Lower Pleistocene (Forest Beds) of Norfolk, England. In the Thames Valley deposits it was contemporaneous with early man, and for a while with *Elephas primigenius*, the hairy mammoth. *E. antiquus* was essentially an animal of warm climate, giving way to the mammoth when the arctic conditions of the glacial period arose.

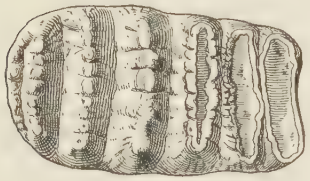


FIG. 20.—Stegodon tooth (× ¼).

In North America, during the cooling to cold climatic conditions of Pleistocene time, there were three species of *Elephas*, of which the most primitive in point of tooth structure was the great imperial elephant *E. imperator*, a migrant from the Eurasian continent. This species appeared in the Lower Pleistocene (Equus or Sheridan beds) and, while it ranged from Ohio to California, was more southern in distribution, ranging as far as Mexico and possibly into French Guiana. In this species the grinding teeth were of enormous size, with very coarse lamellæ and the outer covering of cement was extremely thick.

FIG. 21.—Tooth of *E. imperator* (× ¼).

Elephas imperator was of great size, 13½ feet in height at the shoulder, and the huge, spiral tusks measured 13 feet along the curve by 22 inches in circumference. One tusk in the city of Mexico is said to be 16 feet in length!

Elephas columbi, the Columbian mammoth, is thought by some authorities to be but a variety of *E. primigenius*, the teeth being transitional in the character of the lamellæ between the latter and *E. imperator*. In fact, they greatly resemble those of the modern Indian elephant. *E. columbi* was early and middle Pleistocene in distribution, more southern in range than *E. primigenius*, though the two inhabited a broad frontier belt along the northern United States. *E. columbi* reaches the maximum of evolution in the shortening and heightening of the skull. The tusks in a mounted specimen in the American Museum of Natural History are so huge that their tips actually curve backward and cross each other. They have completely lost their

FIG. 22.—Tooth of *E. columbi* (× ¼).

original digging function, and their use as weapons must have been much impaired. They seem to represent an instance of a certain acquired momentum of evolution carrying them past the stage of greatest usefulness to become an actual detriment to their owner. This may have been an important factor for extinction.

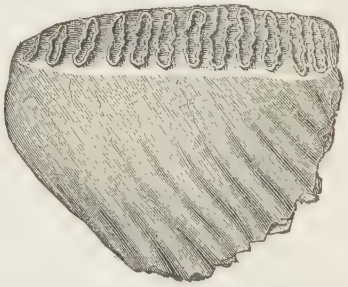


FIG. 23.—Tooth of *E. primigenius* (× ¼); after Marsh.

Elephas primigenius.

The mammoth was not among the largest of elephants, being but little in excess of *Elephas indicus* in height, but with relatively huge tusks exceeding, in some instances, a length of over 11 feet measured along the outer curve. The teeth have the most numerous and finest lamellæ, and in this respect, as well as in the development of hair, this creature shows the greatest degree of specialization as compared with the tusks and skull in the Columbian species. It is curious to note, however, that in three ways one can trace the increasing fineness in the lamellæ of the molars corresponding to the three modes of distribution—latitude, altitude, and time—for the more ancient individuals, living the farthest south and nearest the sea level, have teeth very much like those of *E. columbi*. The increasing fineness of lamellæ is correlated with increasing cold and a consequent change in the character of food plants, as the last of the mammoths fed upon harsh grasses and the needles and cones of the fir and other conifers, mingled with moss. The hairy coat, another adaptation to extreme cold, was of three sorts, an inner coat of reddish wool, next a longer, fawn-colored coat, outside of which were long, black bristles, especially on certain parts of the body, as the neck, back, and chest. It is interesting to note that in the Indian elephant, the nearest living ally of the mammoth, there is, at birth, a complete coat of rather long hair, which is shed in a few weeks, except that in the mountain region of the Malay peninsula elephants are reported to be persistently hairy. This points to an

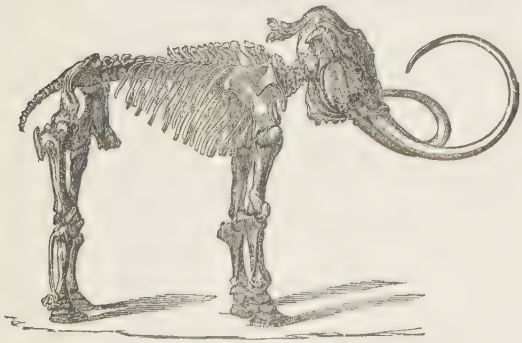


FIG. 24.—St. Petersburg mammoth of 1806.

ancestral hairy condition atavistically developed in later types when necessitated by cold. A similar development is seen in the Manchurian tiger, in form and markings precisely like its tropical cousin, the sleek Bengal tiger, but with a long, thick fur which defies the cold of a climate as severe as that of New England.

The hairy mammoth was circumpolar in distribution, ranging from Europe across the north of Asia as far as 70° north latitude to the eastern part of the United States, its southern limit overlapping the northern range of *Elephas columbi.*

MODERN ELEPHANTS.

The African elephants are the more primitive in the character of the teeth with their broad lozenge-shaped lamellæ, unless, as has recently been suggested, they are in this respect degenerate. The African forms included by some authorities under the genus *Loxodonta* have recently been divided into four species. They are distinguished from their cousins of India by the contour of the head, the greater size of the ears, greater development of the tusks, and the presence of two figure-like processes at the tip of the proboscis instead of but one. African elephants reach a greater size than do those of India, attaining a height of 12 to 13 feet at the shoulders and a weight of over 7 tons.

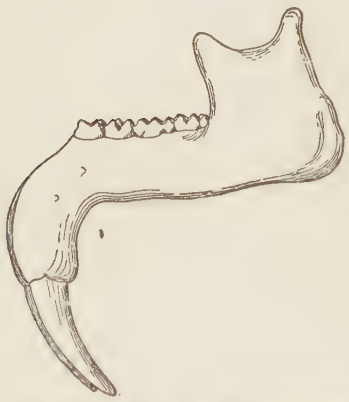


FIG. 25. Jaw of Dionotherium; after Kaup.

The Indian elephant includes but one species, *E. indicus*, of which there are, however, several well-marked castes or breeds, varying greatly in commercial value. In size the Indian elephant rarely reaches 11 feet, averaging about 9 for the males. The high, convex forehead gives the Indian elephant a somewhat nobler, more intellectual cast of countenance than its African cousin, but this character is due solely to the greater development of the air cells in the skull.

Dinotherium.

In the Miocene of Europe, though ranging up into the Pliocene of Asia, is a curious aberrant type, evidently a proboscidian though formerly classed with the Sirenia. This form is *Dinotherium*, and must have been derived from some very early genus, certainly not later than *Palæomastodon.* The teeth differ from those of the elephants in their greater number and in their mode of succession, being

more like those of other mammals. The grinding teeth are extremely simple, the premolars having 3 while the molars have but 2 cross crests with open, uncemented valleys. Tusks are apparently confined to the lower jaw, no trace of upper tusks having been seen in the only known skull, now unfortunately lost. Those of the lower jaw were large and, together with the elongated symphysis, bent abruptly downward, the tips being actually recurved. The skeleton, so far as known, indicates a huge elephant-like body and limbs and the impression is that the creature must have been semiaquatic, frequenting the beds of streams and living upon the succulent herbage which it rooted up by means of its tusks. The contour of the skull is ill known, so that, with the exception of the lower jaw, restorations of the head are largely conjectural. *Dinotherium* died out in the Pliocene, leaving no descendants.

Part III.

MIGRATIONS OF THE PROBOSCIDEA.

In studying the dispersal of a group of terrestrial vertebrates one has to consider not alone the probability of land bridges over which the wandering hordes might pass, but, on the other hand, the existence of barriers to migration other than the absence of these bridges.

The possible barriers are climatic, topographic, and vegetative. Of these the climatic has been given weight, but in the case of the proboscidians the direct action of temperature is relatively unimportant, though the presence of moisture is a prime necessity.

The African elephant formerly ranged from Cape of Good Hope into Spain, while *Elephas primigenius* enjoyed an even greater range in latitude and consequent temperature. The African species has a vertical distribution from sea level to a height of 13,000 feet in the Kilimanjaro region, which also gives a great range of climatic variation. Aridity, however, is a most efficient barrier, not only from its effect upon the food supply, but because water is a prime necessity to elephantine comfort. The Sahara to-day marks the northernmost limit of the African species, the former distribution to the north being by way of the Nile Valley or possibly to the westward of the Great Desert.

Mountain ranges on the whole do not impede elephant migration, except of course such mighty uplifts as the Himalayas. The height to which the elephant wanders in the Kilimanjaro has already been mentioned, while Hannibal took a number of African elephants across the Little St. Bernard pass, which has an altitude of 7,176 feet, in his invasion of Italy in 218 B. C. The Pyrenees, however, seem to have prevented the numerous elephants of France from in-

vading the adjacent Spanish peninsula, as the few species of fossil elephants found therein seem almost without exception to have entered from Africa by way of Gibraltar. The great ranges of mountains in the new world may have influenced somewhat the trend of migration, but were crossed by the proboscidians at will.

Vegetation does constitute a most effective barrier, especially in the case of the tropical jungle of Central America. During the Pliocene, as we shall see, after the land bridge was established, intercommunication between the two Americas was very free. In the Pleistocene, however, this migration of large quadrupeds gradually ceased, so that in spite of the great abundance of mammoths and mastodons in North America none attained a foothold south of the Mexican Plateau. To-day the jungle is absolutely impenetrable for all of the larger mammals except such as may be at least partially arboreal in habits.

The migrations were forced, not voluntary, for it would appear that the mighty elevations of Asia beginning in late Miocene times and the consequent alternations of moist and arid climates, with a strong tendency toward the latter, has caused these great animals to disperse themselves from the rising high lands of central Asia into the more stable lowlands. In these forced wanderings the land bridge between Asia and Alaska was again and again discovered and crossed by the migrating hordes.

The first appearance of the proboscidians is in the Middle Eocene beds of the Egyptian Fayûm district. There we find in *Moeritherium*, the most primitive type, the forerunner of the race. Of the extent of the geographical range of *Moeritherium* and of its successor, *Palaeomastodon*, we know nothing further than that they have only been found within the Fayûm.

During the Oligocene the proboscidians seemingly remained in Africa, though of this we have no record. Early Miocene deposits of Mogara, which lies northwest of the Fayûm some five days' journey, about 75 miles, give us the remains of *Tetrabelodon angustidens*, the next known type in the evolutionary series. From Tunis again this species is reported, being what Professor Deperét calls the ancestral (ascending mutation) race of *T. angustidens, pigmeus*. This race is also reported from the sands of Orleans and from the Burdigalienne of Agles (Aglie, Italy). Thus it seems as though *Tetrabelodon angustidens*, the form with the maximum development of symphysis, were the one to make the exodus from Africa, not as the children of Israel did, by way of the northeast, but by the land bridge connecting Tunis with Sicily and the latter with Italy, and thence by way of Greece to Europe and Asia.

Mammut americanum phylum.

[See chart 1.]

Tetrabelodon angustidens did not go unaccompanied, for another type, *Tetrabelodon turicensis* (=*tapiroides*), found in the Lower Miocene of Algeria, must have traveled into Europe by the same route and about the same time. In *T. turicensis* the grinders are simple in character, as though it had already begun to differ in its feeding habits from its contemporary, in which the teeth are comparatively complex. *Tetrabelodon turicensis* spread during the Miocene over France, Germany, Austria-Hungary, Russia, and as far as southeastern Siberia. The successor of *Tetrabelodon turicensis* was *Mammut borsoni*, covering much the same geographical area as its forebear, being found as far as England to the north and Russia, along the northern coast of the Black Sea, to the east. Geologically it ranges from Lower to Upper Pliocene. *M. borsoni* merges into *Mammut americanum*, the great American mastodon, which outlived the mammoth in the new world. Some teeth found in southeastern Russia have been referred to the American type by Madame Pavlow, who was perfectly familiar with *M. borsoni*. However that may be, the migration of this race was without doubt across Siberia, the Behring isthmus and into the new world from the northwest. The American mastadon's remains have been found from Alaska to California, east to Prince Edwards Island, and from Hudson Bay to Florida on the east coast, while Le Conte reports a specimen from Tambla, Honduras, about 15° north latitude, the nearest recorded approach to South America.

Tetrabelodon, Dibelodon phylum; Tetrabelodon, Elephas phylum.

[See chart 2.]

Reverting once more to *Tetrabelodon angustidens*, we find in it the possible ancestor of all of the later proboscidians, with the exception of the very aberrant *Dinotheres* and the American mastodon phylum. *Tetrabelodon angustidens* was a great migrant, covering most of Europe with the exception of Spain and England. Its descendants diverged along several lines of specialization, as along varied lines of travel, at least one representative reaching North America in the Middle Miocene (Deep River beds), possibly before (Virgin Valley of Oregon, Merriam).[a] The earliest North American form, *Tetrabelodon productus*, resembled its European prototype very closely and gave rise to a remarkable group of four-tusked mastodons which ranged from Nebraska to Florida. From some of the later species arose the *Dibelodon* race with upper, enamel-banded tusks, but lack-

[a] A still earlier type, *Gomphotherium* (*-Tetrabelodon*) *conodon* Cook, has just been described from the lower Miocene (upper Harrison) beds of western Nebraska.

CHART 1.—Miocene-Pleistocene. *Mammut americanum phylum.* + *Tetrabelodon furcensis;* ● *Mammut americanum;* ▲ *Mammut borsoni.*

CHART 2.—Miocene-Pliocene. *Tetrabelodon-Elephas phylum* (part). *Tetrabelodon-Dibelodon phylum.* F Fayûm; ● Old World Tetrabelodon; + Old World Mammut (leading to Stegodon); ○ New World Tetrabelodon; ▲ New World Dibelodon.

ing those of the lower jaw. This genus is reported from the Pliocene (Blanco) of Texas and Mexico and ranges as far south as Buenos Aires in the southern hemisphere. Two South American species are known to us, one *D. andium*, following the chain of the Andes as far south as Chile. This type is often found at great altitudes, a specimen from the Quito Valley in Ecuador, now in the Yale collection, having been found 10,000 feet above the level of the sea.

Dibelodon humboldii was a dweller on the plains, being found in the pampas formation near Buenos Aires, while Darwin records it along the banks of the Parana River in Argentina, and Wallace reports the same species among other remains in a limestone cavern near the headwaters of the San Francisco River in southern Brazil. *D. humboldii*, like *D. andium*, has its origin in the Texas Pliocene, the line of migrations nearly paralleling, the one along the tropical plains, the other along the Andine plateau as far south as northern Chile. With the exception of a lone specimen of *Elephas* reported from French Guiana and the mastodon of Honduras, *Dibelodon* is the only proboscidian of the Neotropical realm. The migration of these great forms occurred in the late Pliocene, and for some reason, evidently climatic and vegetative, the route has been closed ever since. Otherwise it is reasonable to suppose that the elephants and mastodons of the Pleistocene would have spread into South America as well.

In Europe *Tetrabelodon angustidens* had successors in *T. longirostris* and *arvernensis*, the latter ranging over western Europe into England. It did not, however, cross the Pyrenees into Spain. *T. longirostris* and a late mutation of *T. angustidens*, *palaindicus*, made the long journey to the Orient, transferring the evolution from Europe to India. The path of this migration is as yet unknown, as little or no paleontological exploration has been made in the region lying between Armenia on the west, across Persia, Afghanistan, and Beluchistan to the Indus River. This oriental migration must have occurred during the Upper Miocene and was followed by a relatively rapid evolution involving a number of species of mastodons and elephants. *Tetrabelodon longirostris* seems to have given rise to *Mammut*[a] *cautleyi* with a shortened lower jaw, thence through *M. latidens* to *Stegodon clifti*, the transitional form between the mastodons and the elephants. *S. clifti* was followed in succession by *Stegodon bombifrons* and *S. insignis* and finally by the genus *Elephas* itself. *Elephas* proved to be a great migrant, although the stegodont species had spread from their original homes in the sub-Himalayan region eastward through Burma, China, and Japan, and perhaps as far as

[a] These Indian forms agree probably with the American mastodon in having but one pair of enamelless tusks. They may represent the *Mammut* stage but in an entirely different phylum, hence should not bear the same generic name.

Java. *Elephas* later traveled in two directions, westward back to Europe and Africa, and eastward, thousands of miles, into the United States.

Evidence seems to point to an interesting parallelism in evolution between the American elephants and those of Europe, though they were undoubtedly derived from a common ancestry.

THE TRUE ELEPHANTS.

[See chart 3.]

Disregarding for the present the hairy mammoth, *E. primigenius*, two notable types are found in Europe during Pliocene and Pleistocene times. Of these the more ancient is *Elephas meridionalis*, probably derived from *Stegodon insignis* of India and undoubtedly the migratory species over the Persia-Asia Minor route which the remote ancestors traveled in their journey to the East.

Elephas meridionalis ranges from the Red Crag (Upper Pliocene) to the Lower Pleistocene Forest Beds and from England on the north to Algeria on the south, though never gaining a permanent foothold in Africa. *E. meridionalis* is succeeded by *E. antiquus*, a great form with straight tusks, whose geological range is from the Forest Beds to the Upper Pleistocene. *E. antiquus* is found in England, central Europe, as far east as the region lying north of the Black Sea. In a southerly direction one can trace the course of migration through Italy, Malta, Sicily, north Africa, and across the present strait of Gibraltar to southern Spain, where specimens have been found at Europa Point and at Seville. Evidently the Pyrenees proved too great a barrier for a direct migration into Spain, though the invasion was accomplished through this circuitous route. In the islands of Sicily and Malta are found relics of this southern march of *E. antiquus*, not only remains of the normal species, but of its curiously dwarfed descendants, *Elephas mnaidriensis*, *E. melitensis*, and *E. falconeri*, the last only 3 feet high. These types developed through degeneracy after the migration had passed and the line of communication was cut off, leaving Sicily and Malta as small islands. The limited area, scanty food, and general hard conditions were responsible for the dwarfing, precisely as the Shetland ponies have lost the original stature of *Equus caballus*. In the Maltese elephants the diminution in size brings the animal *below* the stature of the ancestral *Mœritherium*, though in no other way is it an atavistic type. Dwarf forms are also found in Crete and Cyprus.

An early form of *Elephas antiquus* evidently gave rise to the modern African elephant through the type known as *Elephas priscus*, included by some authorities in *E. antiquus* itself. The development of teeth of *E. africanus* with relatively few lozenge-shaped

CHART 3.—Pliocene-Pleistocene. *Stegodon-Elephas phylum.* × *Stegodon cliffi*; ○ *Stegodon insignis*; + *Elephas planifrons*; ● *Elephas meridionalis*; ▲ *Elephas antiquus*; △ *Elephas nomadicus*; □ *Elephas imperator.*

ridges seems to be a matter of degeneracy, which casts some doubt upon the value of the subgenus *Loxodonta*. *Elephas africanus* deployed over the whole of Africa with the exception of the Sahara Desert. It also crossed to Gibraltar and spread over most of the Spanish Peninsula. It has since been extirpated, however, in all of the region north of the Sahara. The living Indian elephant exhibits similarity of structure with the *E. antiquus*, a form known as *Elephas armeniacus*, found in Asia Minor, being annectent type. *Elephas indicus* may have come from *Elephas insignis* through the Lower Pleistocene *E. hysudricus*, and probably represents a purely local evolution, not a migratory form.

A most perplexing question arises with reference to the origin of the great North American elephants, *Elephas imperator*, *E. columbi*, and finally *E. primigenius* itself. Emphasis has been placed on the similarity existing between the American and European elephants, though I know of no expression of opinion as to the actual relationship of the forms in question. In tooth characters *Elephas columbi* is certainly suggestive of its European contemporary, *E. antiquus*, while *E. imperator* somewhat resembles *E. meridionalis*. The tusks, which are so important from the developmental standpoint, have apparently been ignored, for the American types have huge spiral tusks, while those of *Elephas antiquus* are nearly straight, and in *E. meridionalis* they show by no means the development of *E. imperator*. It is the writer's opinion that the American forms may prove to be a distinct evolution, having been derived from some such form as *Elephas planifrons*, found in India from the Pliocene of the Siwalik Hills to the Pleistocene of Narbada Valley. We have no record of the migration of *E. planifrons*, but its progenitors and contemporaries ranged, in some cases, as far as China and Japan by way of Burma. This being an accustomed route, *E. planifrons* or a successor might well have ventured beyond China to the northeast through Siberia, across the Bering Isthmus, and thence southward as far as Mexico, giving rise to the American form *Elephas imperator*, which is first reported from the Equus or Sheridan beds (Lower Pleistocene). The known range of the latter is from Nebraska to southern Mexico along the one hundredth meridian, although specimens in the Yale collection were found as far east as Ohio and west to the California coast. We have the authority of Lartet for the finding of a tooth of *Elephas* in the Lower Pleistocene in Cayenne, French Guiana. From the description of the "thick ridge plates" this specimen is evidently that of *E. imperator*, probably a stray to the southward before the conditions which later prohibited proboscidian migration into South America arose. It is the only recorded instance of a true elephant known to me south of the Mexican Plateau. The geographical range

of *E. columbi* embraced the whole southern part of the United States and the highlands of Mexico, including the area covered by *E. imperator*, with the exception of the South American locality.

Elephas primigenius phylum.

[See chart 4.]

Elephas primigenius has been generally conceded to be of Asiatic origin and a near relative of *E. indicus*. The character of the teeth and the presence of hair in the young *E. indicus* are certainly suggestive of relationship. The teeth are also similar to those of *E. columbi* and may represent a further development of the latter type as readily as of *E. indicus* or *E. antiquus*. The presence of hair is an atavistic character developed in *E. primigenius* to meet climatic conditions, and we are by no means sure that *E. columbi* was naked, as this is simply argued from its geographical distribution. The tusks of *E. primigenius*, however, are generally the immense, spirally coiled structures of *E. columbi* and *E. imperator*, though short-tusked specimens do occur, presumably young individuals. In *E. indicus* the tusks are greatly reduced, being absent in the female, often in the male, and are evidently degenerate.

Elephas columbi molars grade into those of *E. primigenius*, and there is preserved in the Yale museum a fine jaw, the characters of which are clearly those of *E. primigenius*, while the teeth are those of *E. Columbi*. In fact, *E. columbi* is often regarded merely as a southern variety of the Siberian mammoth. It seems, however, as though the reverse of this statement might be true, looking upon *E. primigenius*, which is the more specialized form, as the latest mutation of the *imperator-columbi* phylum, originating in North America and becoming circumpolar in its distribution, invading Siberia from the American Northwest. One tooth has been found on Long Island in the eastern part of Hudson Bay, transitional in character between the mammoth and *Elephas columbi*. Lucas supposes that this tooth may have been carried thither with a carcass or a portion of a carcass by the water or ice. This may be true, but upon such slender evidence as this we have sometimes based a route of migration which subsequent discoveries have proven true. It may in this instance imply that the migration was not wholly by way of the Bering route and that the hairy mammoth was indeed a circumpolar form.

Thus it will be seen that these majestic creatures were great wanderers, ranging in the course of time over nearly the entire world. Few mammals have been such world-wide travelers as the elephants, as their record has been exceeded only by mankind, the horses, dogs, and cats, the rhinoceroses and camels pressing close behind. It would seem that in each instance the perfection of the race was in a large measure due to the development of the migratory instinct.

CHART 4.—Pleistocene-Recent. *Elephas columbi primigenius* Group. ● *Elephas primigenius*; + *Elephas columbi*; ////// *Elephas indicus*, present distribution; \\\\\\ *Elephas africanus*, present distribution; dotted area, distribution of mammoth.

EXCAVATIONS AT BOGHAZ-KEUI IN THE SUMMER OF 1907.[a]

(With 10 plates.)

By Hugo Winckler and O. Puchstein.

I. The Discovery of Clay Tablets.

By Hugo Winckler.

Since the beginning of the eighties of the last century, in addition to a deeper study of the ancient civilizations of the countries of the Euphrates and of the Nile, a third region has aroused the interest of investigators. In 1888, A. H. Sayce for the first time collected the inscriptions written in an enigmatic style of hieroglyphics which had become known within a decade and which since then have been coming to light in increasing numbers in north Syria and Asia Minor. It had been contended by William Wright (particularly in his book, The Empire of the Hittites, in 1884) that these inscriptions are connected with the people known as the Cheta or Chatti. This fact is now generally recognized, and adapting the name to its biblical form, Hittim, these people are designated as the "Hittites." Although much careful study has been given to these inscriptions, yet so far there is no definite knowledge as to their meaning.

The interest thus aroused has, however, yielded more tangible results in another direction, and a close examination of records in the Egyptian and Assyrian inscriptions concerning the Cheta or Chatti led to an appreciation of the importance of that people in the history of western Asia. In connection with this research the monuments of Asia Minor were studied, Perrot, in particular, exhibiting a far-seeing view, and it was recognized that the question involved was of a civilization which, in the main, must have embraced all of Asia Minor. The "Hittites" were considered, primarily, as a people of Asia Minor. It became more and more apparent that they entered into the

[a] Abstract, translated by permission, from the German, Vorläufige Nachrichten über die Ausgrabungen in Bog-haz Köi im Sommer 1907. By Hugo Winckler and O. Puchstein. Mitteilungen der Deutschen Orient-Gesellschaft zu Berlin, No. 35, December, 1907, pp. 1–71.

history of Syria since about the sixteenth century B. C., and the significance of this fact was fully appreciated.

From the Tel el-Amarna letters we learn that a people closely related to the Chatti had at that time pushed its conquests as far as the borders of Babylonia. A recently discovered Babylonian chronicle informs us that the fall of the first Babylonian dynasty, of which Hammurabi was the middle king, was due to an attack of the Chatti. As this attack must have taken place about 1800 B. C., we are thus afforded chronologically definite information of the appearance of this people and their empire.

The accounts in all these documents proved that the center of "Hittite" power had been not in Syria, as was at first believed, but in Asia Minor, though in what part of that country could not be definitely settled. Almost all of the inscriptions in "Hittite" script had come from the region of the Taurus, or southern part of Asia Minor, but this region could not have formed the center of a great empire. The other alternative pointed to Cappadocia which, lying in the very heart of Asia Minor, would be a fit center for a civilizing power.

The Tel el-Amarna letters and some clay tablets in cuneiform script found at about the same time as those of Tel el-Amarna in the mound Kul-tepe near the hamlet Kara-eyuk, about three hours east of Kaisariye, bore witness to the strong influence of Babylonian civilization upon the countries of Asia Minor. They showed that the "great King" of Chatti and other rulers of Asia Minor, like those of Syria and Palestine, employed the cuneiform writing in their international dealings.

As early as the thirties of the nineteenth century the ruins of Boghaz-Keui, in the heart of Cappadocia, in the region of the eastern Halys, east of Angora, became known through Texier. They were diligently examined by Perrot and Humann. In the nineties they were visited by E. Chantre, who did some excavating, and by Lieutenant Schaefer and W. Belck, who were all impressed with the importance of these ruins. On my presentation of the matter, Baron W. von Landau offered the means for a trip of inquiry. The required irade was speedily obtained with the aid of the imperial embassy in Constantinople, and thus I reached the ruins in company with Th. Makridy Bey in October, 1905.

The very extent of the ruins indicated that it was a place of unusual importance and that it represented one of the centers of "Hittite" civilization. The prospects of epigraphic acquisitions were very favorable. In the three days during which we could examine the ruins some thirty fragments of clay tablets were discovered, some of them picked up in our presence. In some cases their shape showed that they were parts of tablets of extraordinary size. Ac-

cording to the assertions of the inhabitants of Boghaz-Keui and of other visitors, similar finds had previously been made. During the excavations of the following year (1906) there was a rumor of large bronze finds, consisting of axes and horse trappings. One of these ax-shaped objects is in the Museum of Berlin (fig. 1).

The finds made at our first examination of the ruins promised rich booty of documents in cuneiform script, and through them the establishing on the soil of Asia Minor of a definite historical center that might possibly be connected with other accounts concerning "Hittite" history. The presumptive size of the tablets and the character of the script recalled some of the letters of Tel el-Amarna, so that they could be assumed to be of the same period. Two other facts pointed to a connection between them. All the fragments found at Boghaz-Keui were inscribed in an unknown language, but they were too small to afford connected stories. A chain of circumstances, however,

FIG. 1.—Flat bronze hatchet from Boghaz-keui. ⅔ natural size.

indicated that they were in the same language as two documents of Tel el-Amarna (the letter of Amenophis III to Tarchundaraus, King of Arsawa, and the one in which the prince Lapawa is mentioned), and which goes by the name of the "Arsawa language." This again pointed to an identical period for both sets of documents and a possible closer connection between them. This impression was confirmed by three small pieces, which, by their very appearance and the quality of the clay, strongly recalled the Amarna tablets, but more so by their contents, which were in the Babylonian language, and formed portions of letters to a king.

On the basis of these results the Society of Explorations in Western Asia (Vorderasiatische Gesellschaft) and some of its members provided the means for further excavations. This work was undertaken in the summer of 1906 and resulted in fixing the site and determining its importance and there was discovered a large number of royal documents. For a continuation of the explorations on a larger scale

the German Oriental Society (Deutsche Orient-Gesellschaft) granted the means, while the German Archeological Institute undertook the solution of the archeological problems connected with the task. Thus the work could be taken up, with increased funds, in the summer of 1907. The excavations were carried on as enterprises of the Ottoman Museum, under the direction of Th. Makridy Bey, to whose singular ability in dealing with the people much of the success is due.

The excavations were naturally begun at the point where the tablet fragments had been found, on the slope of Boyuk-Kale (pl. 1). This is a mountain which had been fortified as a citadel and formed the northeast corner of the city wall. The work was carried on from the base upward. The higher the digging ascended the larger was the size of the tablets found, till in places large tablets were ranged in layers. There is no question that we have here to do with the remains of royal archives, though they represent only a small remnant of the original contents.

About midway of the declivity was found the document which established the fact that the site represented the capital of the Chatti empire. The contents of this document were not new; they were in Babylonian language and writing, and formed parts of the treaty of Ramses II with the Cheta King Chetasar, as he has been usually called, or Hattusil, as now proven by the cuneiform script. The text had long been known, being inscribed on the walls of the temple of Karnak.

It was thus ascertained beyond doubt that the tablets belonged to the royal archives and that consequently the site represented the capital. But the question still remained, what was the name of this most important center of the earliest history of Asia Minor, whither once went the embassies from the courts of Thebes, Babylon, Asshur, and whence were started undertakings so decisive for the destinies of the countries of Western Asia? The customary designation of countries in the new documents is "the country of the city N. N." The oriental conception underlying this expression is that a "country" is a district which has for its center and seat of the ruler, a city (machazu) in whose sanctuary the god has his earthly habitation, with the king as his representative and plenipotentiary. A natural consequence of this view is that country and city bear the same name. This observation led to the surmise that the name of the capital was the same as that of the land, Chatti. Subsequently this was confirmed by documents which told only of the city of Chatti and its principal divinity, Teshub, who was already known as one of the most important gods of these and other "Hittite" peoples.

The documents found on the slope of Boyuk-Kale were of the three Chatti kings who were known from the Ramses treaty, though those of Hattusil, the last of them, seem to predominate.

BOYUK-KALE FROM THE NORTHWEST. *a*. WHERE CLAY TABLETS WERE FOUND. *b*. THE GREAT TEMPLE. TO THE LEFT OF *b*, HEADQUARTERS OF THE EXPEDITION.

A still larger deposit of tablets was found in the eastern addition of the large building, presumably the principal sanctuary of the God Teshub. Here, too, the documents of Hattusil predominated, and there were pieces pertaining to his two successors, though not an inconsiderable portion belonged to the reign of his two predecessors, particularly Subbiluliuma the first. Other places, besides these two main deposits, yielded considerable finds. Thus one of the gates furnished a large doom book with the royal seal of Arnuanta. (See below.)

The short time that could be devoted during and since the excavations to the investigation of the material has permitted only an examination of those documents which appeared important, especially such as might shed light on historical conditions. A detailed and exhaustive study of the new-found archives must be preceded by the decipherment of the language and will require the cooperation of many workers for a long time. Even the few examples of the contents here given must be taken only as provisional.

But even to convey an adequate idea of what has already been studied is not easy in the present limited space. It will be seen, for instance, that the Tel el-Amarna finds, as well as many data of the Assyrian inscriptions, find their commentary in the new texts. It would be an instructive task to illustrate by comparative examples this unique interlinking of records, but this would require much more space than is here available, and a more thorough investigation of the documents than has been hitherto possible.

The foremost result obtained is the chronological dating of the documents and through this the defining of the city in its constituent parts. There are documents of the reign of seven kings, representing five generations. Four of these kings were already known from the treaty of Ramses, though their names are only now definitely identified. In the uncertain Egyptian script their names were read, Sapalulu, Maurasar, Mautenel, Chetasar. The order as now established is Subbiluliuma, his two sons Arandas and Mursil, followed by his two grandsons, Muttallu and Hattusil, sons of Mursil. The genealogy of the sons of Subbiluliuma begins with him only; his grandson, Hattusil, names the great-grandfather of the same name, not however as the "great king, King of Chatti," but merely as "King of the City Ku-us-sar" (otherwise unknown). He was probably one of the many city kings who appear as vassals of the "great King," while his son Subbiluliuma was the founder of the dynasty. He had a long and successful reign. The Tel el-Amarna finds contain one or two letters of Amenophis III to him. The new documents show that his reign extended at least to that of Amenophis IV. A whole series of events are common to the Amarna letters and the accounts in the Chatti archives. Here is recounted the advance of the Chatti King

on Mitani after the death of its king, Tushratta. Founders of dynasties in the Orient are frequently also great conquerors, as in the case of Subbiluliuma. His supremacy is recognized by Azir, ruler of the Amorites, and by other princes of Syria, who in the Amarna letters ask the king of Egypt for protection against him. Mitani, until then an independent state, and under Tushratta victorious over the Chatti, succumbs later, and is completely reduced under his supremacy.

The reign of Arandas, son of Subbiluliuma, seems to have been of short duration. His successor was Arandas's brother Mursil (hitherto read Maurasar). There are quite a number of documents relating to Mursil's reign, but much fewer than of the reign of his father and of his son Hattusil. This would lead to the conclusion that Mursil's reign was shorter than those of either Subbiluliuma or Hattusil, though not absolutely a short one. One document seems to give a survey of the first years of his reign, reaching down to his tenth year. It contains references to the subjection of Mitani by his father and to his own relations with Arsawa, and to a number of territories not hitherto known, such as Gasga, Tibia, Zichria. A still more obscure passage in the document seems to bear on the war with Egypt which resulted in the famous battle of Kadesh.

Mursil's successor was at first his son Muttallu. This is already mentioned in the treaty of Ramses and is dwelt upon by Hattusil in several documents. What his end was is not yet clear. His reign could have lasted but a couple of years. The Amarna documents relate that he deposed one of the Amurri (Amorite) princes and put another in his place. A document of his time contains an enumeration of the Chatti pantheon.

Muttallu was succeeded by his brother Hattusil, who is known through his treaty with Ramses. The larger portion of the archives belongs to his reign, which must have been quite an extended one. The documents give information concerning the most important events of that period. Under him the relations with Amurri were regulated anew. The most important event under Hattusil was the making of a treaty of friendship with Egypt. This is referred to in many letters. The document, which may be considered as the Babylonian text of the treaty, is perhaps merely a preliminary exchange of notes. The negotiations preceding the conclusion of the treaty were carried on, as seen from parts of other letters, with great deliberation, as becoming the dignity of both chanceleries. Even the queens participated in the great event, for Naptera, the wife of Ramses, expressed her joy over it to her "sister," Puduhipa, the spouse of Hattusil, in a special letter.

The relations with the other great powers is illustrated by a letter to the King of Babylon; while a fragment of a letter from the Babylonian King, Katashman-turgu, to Hattusil, shows that the

friendly feeling between them was mutual. The constantly growing power of Assyria must have drawn them to one another. The Babylonian King to whom Hattusil's letter is addressed is not named, but must have been Katashman-buriash, son of Katashman-turgu, who is known as an adversary of Shalmaneser I of Assyria. This letter, which comprises upward of 160 long lines, while recalling the Amarna letters, differs from them in its purely political contents. There is no haggling about dowries, or presents promised and not received, as in the long letters between Tushratta and Amenophis III and IV. In Hattusil's letter to the Babylonian King weighty matters of state are discussed, and, especially, information concerning the influence on the succession to the throne exhibits the politics of the great states in their mutual relations:

* * * When thy father died I mourned like a good brother * * * and I sent my messenger and wrote to the notables of Karduniash (Babylonia) as follows: "If you do not recognize [the son] of my brother as King, I shall be your enemy. [But otherwise] if any foe attacks you or is hostile against you, I shall come to your aid." * * * Neither can the people of Chatti command (coerce) those of Karduniash, nor those of Chatti. I wrote to them (the people of Karduniash) with a friendly intent that they may recognize the posterity of my brother Katashman-turgu. * * * As to what my brother writes me that I have stopped diplomatic relations, I did it on account of the Beduin peril (*Ki ah-lamu*—the Aramean Beduins—*Nakru*). * * *

In another passage of the letter Hauttsil informs the Babylonian King about his alliance with the King of Egypt, while still another paragraph treats of a complaint made by the Babylonian King on account of the assassination of trading people (members of a caravan) on their way to Amurri and Ugarit (northern Phenicia, etc.). The writer refutes the possibility of any responsibility resting on the Chatti territory and points out that the murderers should be delivered to the relatives of the murdered.

An insight of wide range into the history of the time is afforded by the following sentences:

I will, furthermore, say to my brother that as regards Banti-shinni, of whom my brother writes, he "disturbs the land." I asked Banti-shinni, and he answered, "I have a claim of 30 talents of silver against the inhabitants of Akkad." But now, since Banti-shinni has become my vassel, my brother may enter a suit against him and he shall answer in the presence of thy ambassador, Adad-shar-iiani, and before the gods [that is, in a formal court action] concerning the disturbances of the country of my brother. And if my brother will not himself prosecute the action, then let thy servant [official] who has heard that Banti-shinni has molested the land of my brother come and carry on the action. Then I shall call Banti-shinni to answer. He is my vassal. In molesting my brother does he not molest myself?

This Banti-shinni is known from other sources, and it will later be seen that he, Prince of Amurri, the Amorite, is one of the successors of Aziri, known or notorious from the Tel el-Amarna letters. Thus

the former surmises about the invasions of the different Semitic migrations are raised to certainties. Since the eighth century B. C. the "Arabians," as invading and conquering Bedouins, formed border states between the settled territory and the steppe. Previous to that the "Aramean Bedouins" played the same rôle. A document of the time of the dynasty of Hammurabi relates that "Amurru" were roaming in the steppe, playing the same game. Since at that time the entire Orient, Babylonia included, must have been overrun by a population that was racially related, the conclusion suggested itself that the Semitic stratum was then in a process of "immigration." To it belonged also the Habiri-Hebrews (a substratum of which were the Israelites), of whom there is mention in the Amarna letters. It is now seen that the ruler of the Amorites is not confined to the hinterland of northern Phenicia, as related in the Amarna letters, but that his territory extends to the borders of Babylonia; that is, he is lord over the great Syrian Desert and its borders. He has a claim against the inhabitants of Akkad, a city of North Babylonia. It shows the spread of a people under the name of "Amorite" from Babylonia to northern Palestine. And this development is of the highest importance for the solution of ethnological problems of the Old Testament.

Hattusil's letter then treats of a physician (asu) and an exorciser (ashipu) who had been once sent to Muttallu and had not yet returned. The exchanging of physicians is also referred to in the letters from Egypt. Then the letter again passes into the field of politics and Hattusil gives expression to the paternal benevolence he feels for his young friend and "brother," encouraging him to attack the country of the enemy, by which very likely Assyria is meant, which was the adversary of both.

Hattusil's reign thus exhibits a decline of the Chatti power. The rising power was then Assyria, under Shalmaneser I and Tukulti-Ninib, upon whose death it likewise collapsed.

The reign of the two successors falls in this time. First came Dudhalia, Hattusil's son. One of the larger documents or edicts mentions Puduhipa (his mother) as coregent. As the queen appears in the same rôle under his successor, we have to assume that this was not an exception, but, as elsewhere (for instance, in Aribi, with the Nabateans, the Ptolemies), that it was the rule. The queen shares in the power of government by her own right, not as wife of the reigning king, for it is the mother who is named in close relation to her son. So, also, as regards Egypt, Tushratta, in a letter to Amenophis IV, appeals to Queen Teyi, and in one of the Tel el-Amarna letters the Babylonian King Burnaburiash complains that this same queen has not shown sufficient interest in his fate. The letter of Naptera to Puduhipa, mentioned above, in which she expresses her

satisfaction over the concluded alliance, would show that queens acted independently even in the lifetime of their husbands.

The edict of Dudhalia seems to bear on the regulation of internal affairs concerning the possessions of powerful subjects, and enumerates many cities and places, closing with the names of witnesses.

A treaty (in private possession) with the King of Aleppo (Halab) containing, like other similar documents, an historical introduction seems likewise to have been drawn up during his reign.

Dudhalia's son and successor, Arnuanta, is at present known only from three documents—two fragments of edicts and the doom book found in the gate of the inner wall. The latter bears the royal seal with a Hittite and cuneiform legend. The former is broken off; the latter may be read:

> [Se]al of the edict (tabarna) of Arnuanta, great King, son of Du-u[d-ha-li. [S]eal of lady Ta-wa-ash-shi (??), lady Mu-ni-Dan, great Queen, * * *?, daughter of Du-ud-ha-li-i[a].

Was the first of the two ladies named the mother—that is, the wife of Dudhalia? His own wife was also his sister—another instance of marriage between brother and sister in the royal house—which here, as among the Pharohs, may have had a mythological reason. The Chatti King, too, was the "sun"—like the Pharaoh or Inca.

There seem to be no other accounts of this reign. The reign of Arnuanta in all probability coincided with the great retrogression of Assyria after the fall of Tukulti-Ninib. As Egypt was likewise weak at that time, it is to be assumed that the territory of the Hittite peoples was not much exposed to its influence from about 1250 to 1150 B. C., and as a consequence we have no records for that period. It is only under Tiglath-Pileser I that we have further accounts, from which fact it may be concluded that the Chatti land also has passed through great revolutions which led to the decay of the state. Tiglath-Pileser defeated the Chatti King and was thereupon recognized by Egypt as the legitimate successor to the Chatti claims in Syria and northern Palestine. Henceforth "Chatti land" is for Assyria a territory standing under Assyrian supremacy, but the term is also limited to Syria and northern Palestine. In Asia Minor there are now for Assyria only "Muski," who appear in place of the former Chatti state.

Alongside of Chatti, the state of Mitani seems, according to the Amarna letters, to have played the most important part. The numerous and lengthy letters of King Tushratta and the similar relations to Egypt entertained by his two predecessors warranted this conclusion. It seemed strange that this correspondence broke off immediately after the accession of Amenophis IV.

It was possible to infer from other documents that the territory of Mitani had fallen to rising Assyria, which shortly before was its

inferior in power, since Tushratta has been in possession even of Nineveh. From other documents it can be seen that a people such as are shown to have been in Mitani was spread as far as the borders of Babylonia and since, according to the Amarna letters, the same fact may be assumed for Palestine, it may be concluded that previous to the Amarna period a people to whom the name of "Mitani" was applied had carried on a large migration or conquest.

The treaties between Subbiluliuma and the successor of Tushratta partly confirm these conclusions and partly put them in a new light. In particular a new light is shed on the question of the composition of the population of Mesopotamia and Syria.

In the first place the political conditions are fully explained through the treaties. Their historical introductions contain accounts of the development of affairs and, in a measure, give a survey of the history of the state of Mitani. The cessation of information concerning Tushratta in Tel el-Amarna becomes clear; he must soon have found his end of which the treaty speaks. That there should be no correspondence between the successors of Tushratta and the Egyptian King is understood when one reads in the treaties that Mitani after a period of anarchy came under the supremacy of Chatti and therefore could not hold direct diplomatic relations with the Egyptian court. Thus these data form a commentary to those letters of Tel el-Amarna which bear on the affairs of Mitani and Chatti, that is, north Syria. The same countries and the same persons are met with in them, and we see how the individual princes are drawn hither and thither between the great powers, shaping their conduct according to the condition of affairs.

The narrative part of the treaty relates how Tushratta, the King of Mitani, rose against the King of Chatti, whereupon the latter inflicted depredations on the left bank of the Euphrates (the territory of Tushratta) and annexed the mountain range of Niblani. But Tushratta was defiant and threatened to retaliate by plundering the right bank of the Euphrates (the territory of Chatti). The record then goes on to say:

> The great King (of Chatti) defied him. For at the time of the father of the King of Chatti (that is Hattusil I) the country of Isuwa rebelled. People of Chatti went to Isuwa (because) the people of the city * * * had rebelled at the time of my father. But the sun (designation of the King of Chatti) Subbiluliuma defeated them. At that time the people who escaped my hand went to Isuwa * * *.
>
> But the sun Subbiluliuma undertook an expedition against the defiant king Tushratta. I crossed the Euphrates. I marched against Isuwa and visited punishment upon the entire Isuwa. I made them a second time my subjects. I inflicted punishment upon all the people and lands that at the time of my father went to Isuwa * * * and subjected them to Chatti. The lands which I captured I released, they remained in their place. But the people whom I released migrated to their people and the Chatti took possession of their country.

The occurrence which is here alluded to illustrates peculiar conditions in the old Orient. An entire people migrates, seeking new habitations in a land of foreign lords. There was no lordless land in the old Orient, although the more frequently these lands were really unprotected by the lords. A similar movement (in which Isuwa is also mentioned) is recorded in a treaty which regulated the relation of the Chatti King Mursil or Hattusil (probably the first) to Sunassura of Kizwadna. This country, too, seceded at the time of the "grandfather" (of the Chatti King) to the Charri, and this was accomplished by migrations to Isuwa. The biblical migrations of Abraham's people to Palestine and Egypt and of the Israelites from Egypt appear in a new light, just as here a discontented people seeks a home in a defenseless or poorly protected land of another lord, whose rule is less oppressive and allows of freer development, so did the Israelites migrate to another land.

The historical introduction of the treaty describes other expeditions and conquests of the Chatti King which were provoked by the hostility of Tushratta and mentions other countries and persons who are in part met with in the Amarna and Assyrian inscriptions. The document then reviews the reason for the present treaty, at the same time giving an account of the end of Mitani:

> When his son and his servants had entered a conspiracy and killed his father, Tushratta, * * * Teshub decided the case in favor of Arbatama, and the land of Mitani was entirely ruined. The Assyrians and Alsheians divided it. But the great King [of Chatti] until then did not cross the Euphrates nor exact taxes and tribute from the country of Mitani. When he learned of the poverty of Mitani he sent them palace people [that is, members of the royal house], cattle, sheep, and horses, for the Charri people got there into misery. Suttatava, together with the notables, sought to kill Mattiuaza, the son of the King. He fled and came to the sun Subbiluliuma. The great King said: "His case was decided by Teshub, taking the hand [helping] of Mattiuaza, son of King Tushratta, I place him upon the throne. * * *" The great King gave the country of Mitani, for the sake of his daughter, a new life. I took Mattiuaza by the hand and gave him my daughter for a wife.

Here ends the introduction to the treaty. There then follow the conditions regulating the relation of Mattiuaza to his protector. He enters into a "sonship." His empire is thus not properly a vassalage, but something like a protectorate. He is to dismiss all his wives and have only the daughter of the Chatti King as wife. Their offspring shall be heirs to the throne. Between Chatti and Mitani shall be friendship. Regulations regarding the extradition of "fugitives," similar to those of the treaty with Egypt, are agreed upon. At the conclusion the gods of both countries are invoked as witnesses of the alliance.

The account of the events after Tushratta's death opens new vistas into the conditions of the various countries. The Charri must have

played a part in Mitani, which accounts for the mentioning of their King Artatama at the beginning of the treaty. They may represent a people living under their own King toward Asia Minor, but who overran Mitani and seized the reins of government.

There are scarcely any documents bearing directly upon Assyria, though a fragment speaks of "Adad-nirai, your lord," which may be part of a letter from Subbiluliuma to that Assyrian King.

From the data known before the present excavations were undertaken it was expected that instead of the center of the Chatti Empire, the country of Arsawa (Arsapi) would be mentioned. It was not surprising, therefore, to find this country often referred to in the new documents, and while it seems to have always been under the influence of the King of Chatti, it must have been an independent state, for Amenophis III writes directly to its King, Tarchundaraus, and a diplomatic intercourse could be maintained only with independent states. The country must have been situated somewhere within Asia Minor. Fragments of a lengthy tablet (in the Hittite language) record the affairs of Arsawa. There is mention of King Alakshandu, evidently a contemporary of Hattusil (and probably also of Mursil, who is likewise mentioned), and who was at all events a successor of Tarchundaraus, as the latter must have been a contemporary of Subbiluliuma.

Less frequent is the occurrence of Alashia-Cyprus, which in the Tel el-Amarna finds is represented by its own letters. In the fragment in which it is mentioned it is referred to, as in the Amarna letters, as furnishing copper, its main product.

Aitakuma, Prince of Kinza, known from the Amarna letters, is met with in the historical portion of the Mattiuaza treaty and elsewhere. His son, Shama-Teshub, is represented by his own letters.

Most remarkable is the overlapping of both archives (of Tel el-Amarna and Chatti) in their accounts concerning the country of Amurri and its princes. The importance inherent in the "Amorites" as old settlers of Palestine and Phenicia is now augmented when it can be seen how everything developed from the conditions of a great immigration, and what attitude the Amorite people of Canaan and Phenicia assumed toward the other peoples of this immigration, including the Habiri.

In the Amarna letters Aziri, Prince of Amurri, plays in northern Phenicia the part of a disturber of the peace. Aside from several of his own letters to the Egyptian court, he is very frequently mentioned in the letters of the other princes as the soul of all disturbances. The capture and destruction by him of the city of Sumur in the territory of Byblos forms the subject of many complaints and much correspondence. The court of Egypt ordered him to rebuild

(though not to vacate) the city, and finally summoned him to appear at court and defend himself. After many subterfuges and delays he went to Egypt and succeeded in exonerating himself. But the accusations of his opponents that he was in sympathy with Chatti were as little unfounded as in the case of the Prince of Kinza. Subbiluliuma and his successors themselves state that Aziri at last became a faithful vassal of Chatti and so also remained his successors. The conditions of his country are touched upon in several royal edicts and treaties—composed in Hittite and Assyrian—so that we obtain a kind of chronicle of Amurri from the time of Subbiluliuma and Aziri down to that of their great-grandchildren. Thus Mursil, addressing Abi-Teshub, the grandson of Aziri, says:

> Aziri, thy grandfather, rebelled against my father. My father reduced him to submission. When the kings of Nuhashi and Kinza rose against my father, thy grandfather Aziri did not rise. When * * * my father made war upon his enemies, thy grandfather Aziri likewise made war on them * * * And my father gave protection to Aziri and his land * * * 300 (shekel) of gold my father imposed upon thy grandfather as a present and tribute. He paid them annually, never withheld them, never angered him * * * As thy grandfather Aziri behaved toward my father, so he behaved toward me. When the kings of Nuhashi and Kinza again rose against me, thy grandfather Aziri and thy father Du-Teshub did not join them.

In a document, written in the Hittite language, belonging to the time of Dudhalia, the name of one of the Amurri Kings, Benteshina, is the equivalent of the Assyrian Put-ahi, from *putu*, front, and *ahu*, brother. The name Benteshina is not "Hittite" in the narrower sense (Chatti), but belongs to the other of the two known languages—the one which until now was designated as "Mitani." It is therefore certain that the Amurri princes at that time bore names in this language.

From this fact may be derived conclusions of great significance for the ethnology of the countries here discussed. Until now the Semitic constituents of the Syrian population, sufficiently known, were considered as the only or predominating factors in western Asia. The new information compels us to give also the other element, the "Hittite," its due importance, and allows us to distinguish new components in that general and indefinite ethnic name.

The designation "Mitani" has been a provisional one. It can be now established that the propagation of that language, and also of the people, extended from the borders of Babylonia to Egypt. This propagation must have been old. According to a Babylonian chronicle a great conquest by a people bearing the name of Chatti took place at the end of the first Babylonian dynasty; that is, soon after 2000 B. C., or, at the latest, at 1700 B. C. From this time on the name Chatti must be connected with the populations that overran

western Asia. It is obvious that this "Hittite" population could not have remained for a millenium and more as a single united people. The question is, What is the relation of our Chatti of Subbiluliuma's dynasty and their language to those conquerors?

In the first place, it is clear that we have here to do with two different languages, as different as Latin and Greek. The "Mitani" tongue must be considered as the earlier one in western Asia; it is the language of the older strata of the migration. The question is only, Was it the language of the "Chatti" conquerors at the end of the first Babylonian dynasty, or did these Chatti already speak the "Hittite" language? This question can not here be definitely decided. For the present it may be stated that in the Assyrian inscriptions Mitani is considered as the language of Mesopotamia, and as thus having a sure footing within the narrower sphere of Babylonian civilization, while the Tel el-Amarna documents attest to its use also in Palestine. Taking this evidence in connection with the new information it may now be stated as a certainty that before the Tel el-Amarna period a people, such as may be comprised under the name of "Hittite," and which was identical with the one until now best known by the name of "Mitani," spread as far as the southern borders of Palestine.

From this conclusion it follows that we have to count with a very considerable non-Semitic layer in the population of Syria over which the Israelitish or "Hebrew" layer was later superimposed. The differentiation of the component parts of this "Hittite" layer can only be undertaken after a more thorough investigation of the language of Mitani and the "Hittite."

In the accounts of conditions after Tushratta's death the Charri play a part. There is no question that they were a population of Mitani, forming the ruling or aristocratic class. By the side of this there is also a people of Charri, evidently closely related to that of Mitani, having its own kings, thus forming a state by itself. The simple explanation would be that a great Charri conquest took place, which concerned Mesopotamia and the adjacent countries. From their royal family Tushratta became king of Mitani, thus attempting to support his power by the part of the population that was older than the Charri (but likewise "Hittite"). That would have been the usual course of things under such conditions.

As to the situation of the state of Charri, it must be placed in the immediate neighborhood of Mitani, in Mesopotamia, rather northward than southward—that is, in the direction of Armenia. But here we recall that the Egyptian accounts also mention a country of Cha-ru, and both names can not well be separated. In these records, however, Cha-ru was taken as the designation of southern Palestine, which would carry the name a long distance away. This difficulty is

removed by our assumption of an extensive immigration and conquest. The designation of southern Palestine as "Charu" in the Egyptian accounts would only show that just then (in the time of Sety I), or shortly before, the Charu conquest took place, which extended the name Charu to the southern borders.

But a difficulty arises when a detailed separation of the several strata of the population is attempted. In the first place there are the two languages—the "Mitani" and the new "Hittite." They do not seem to be related, but whether they belong to different families of languages must for the present remain undecided. The "Hittite," the former "Arsawa," has been claimed for the Indo-European family of languages (compare Knudzon, Die Zwei Arsawa Briefe). It is rather premature, however, to pass judgment on this question before the new documents have been subjected to a closer study. There can be no longer any doubt that we should assume the existence here of an Indo-European population. As guardians of the treaties between Chatti and Mitani (Mattiuaza) the gods of both countries are invoked. These are, in the first place, the divinities established of old, that go back to the earlier periods of purely Babylonian influence, for they bear pure Babylonian names. Then comes the Teshub-circle, evidently the properly constituted national deities of both countries but likewise belonging to an older stratum. In the midst of these names we suddenly find, in the Mitani portion, two names hardly to be expected in this connection:

1. ilâni-mi-it-ra-ash-shi-il u-ru-w-na-ash-shi-el (variant: a-ru-na-ash-shi-il).
2. ilu (!) in-dar ilâni na-asha-a[t-ti-ia-a]n-na (variant: in-da-ra na-sh[a]-at-ti-ia-an-na).

That is, Mithra, Varuna—whose identity can not be doubted, though the rendering of his name offers some difficulty—Indra, and a fourth divinity, who from the context must belong to the same group.

It is impossible here to enlarge upon the significance of this fact as evidence of the existence of an Indo-European people in western Asia. Suffice it here to answer briefly the question: To which part of the population do these divinities belong? The god of Mitani, as also of Chatti, is Teshub; he would thus represent the older layer. The layer represented by the Indo-European divinities must have been the dominant and aristocratic one, since its gods are invoked by name. This points to the Charri, who must therefore have been Aryans.

Since our Hittite language is Indo-European, we shall further assume that the same population also overran the Chatti land, so that for Chatti, as well as for Mesopotamia and Syria-Palestine, two strata must be assumed, the earlier Teshub-people and the younger Charri. With this assumption accords the use of the Hittite language in Palestine and the character of proper names, such as Mattiuaza, or that

of a Syrian prince, Namiawaza. On the other hand, none of the names of the royal family of Mitani and Charri is formed with that of the principal god Teshub, while that of the oldest member is Saush-shatar, the second part of which corresponds to Aryan Kshatra, as rendered in cuneiform script. The same observation is made with regard to the members of the royal family of Chatti.

Considering the ethnology of earliest Palestine, it hardly need be pointed out that the Charri are the Horim of the Old Testament.

The two strata of people, represented by their languages, may be designated as the Aryan and the Teshub. There are indications that the Teshub-strata was superimposed upon a still older one. The chief god of Chatti, as well as of Mitani, was Teshub, the national sanctuary at the city of Chatti being consecrated to him. But other divinities are recorded, bearing in part purely Babylonian names (as Zagaga), who must belong to the earlier periods of Babylonian influence. A predominating part is also played by the cult of the sun. The "sun of (the city of) Arinna" is frequently mentioned, and seems to rival with Teshub for the supremacy, so that it must have been a famous sanctuary of high antiquity.

Compared with the rich harvest of written documents, the finds of sculptures were not large. The immense area of the temple, the principal building, yielded nothing of the kind. It must have been previously ransacked. Only in the court of the temple were there found remnants of a water basin. One piece of the basin lay on the surface and was formerly considered as the "throne;" it is as such described by Perrot and Chipiez. One end is formed by two lions with their fore parts turned outward. The other end is represented by a corresponding figure of a lion, only of a considerably larger size. Their relation is that of a full-grown animal to a young one (pl. 2, figs. 1 and 2). Aside from this the city gates furnished some of the best examples of Hittite art. A specimen is here reproduced, the lion's gate (from a drawing of O. Puchstein, pl. 3). The finds at other gates brought to light by the excavations of the Archeological Institute are better reserved for discussion by specialists.

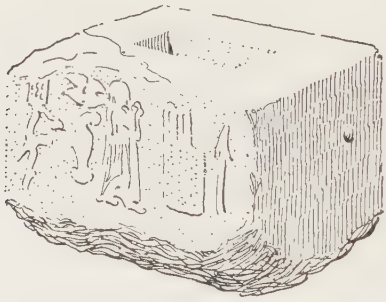
These objects will probably have to be placed in the same period as the documents. To an earlier stage of art belong two stone blocks found on the mountain declivity above the "temple" (pls. 4 and 5). They apparently served as bases of statues. Though the general meaning of the representation is evidently a symbolical scene, yet the interpretation of the individual objects will present many riddles. No indications of the former placement of the two pieces could be found. Further search resulted only in finding the head of a clay statuette of the Hellenistic period. There was a rich harvest of potteries. All the different epochs from the Hittite to the Galatian periods are probably represented by numerous samples. The treatment of this subject must likewise be left to specialists.

FIG. 1.—TWO SMALLER LIONS OF THE WATER BASIN.

FIG. 2.—LARGER LION OF THE WATER BASIN.

VIEW OF THE OUTER SOUTH GATE, WITH LIONS, AND OF THE LEFT TOWER.

HITTITE RELIEF DISCOVERED ABOVE THE TEMPLE.



HITTITE RELIEF DISCOVERED ABOVE THE TEMPLE.

II. The Buildings of Boghaz-Keui.

By O. Puchstein.

That the Imperial Archeological Institute was enabled to undertake the solution of the archeological tasks connected with Prof. H. Winckler's new explorations in 1907 was due to the kindness of Dr. O. Hamdy Bey, director-general of the Imperial Ottoman Museum, and was made possible by the special grant of His Majesty, the German Emperor. Some of the expenses were defrayed by Professor Winckler from funds placed at his disposal.

While Makridy Bey, of the Ottoman Museum, had started the new excavations in April, the government archeologist, Daniel Krencker, and Dr. Ludwig Curtius, who were at first commissioned by the central direction of the institute, could not set out before the end of May and begin their work before the first of June. Doctor Curtius remained on the scene till the end of August. After the end of June Krencker was assisted by the government architect, Heinrich Kohl, and after his departure, in the middle of July, was superseded by him. From the middle of July the secretary-general of the institute was digging and working alongside of Kohl, both carrying on the excavations tentatively begun by Makridy Bey and Winckler in 1906.

It was a great advantage for our archeological investigations that Winckler's discoveries had determined the period and the sphere of civilization to which the finds of Boghaz-Keui belonged. On this sure basis Doctor Curtius studied the well-known rock reliefs and examined the new sculpture finds. He gained much new material for defining the authentic Hittite monochrome ceramics and the multiform "Phrygian," faintly tinted potsherds, so that the question as to whether the latter belonged, in part at least, to the Hittite period of Boghaz-Keui can now be settled.

The additions to the knowledge of Hittite architecture in Cappadocia made by the work of the institute is of much scientific importance. The buildings were large and monumental, and acquaint us with a new style of oriental architecture.

Considering first, from an archeological viewpoint, the buildings, there may be recalled the data given by Winckler about Boyuk-Kale, the main acropolis of Chatti, where the first more recent archives were found. We ourselves did not work on this site of the city district, but the examination of the remains which Makridy Bey brought to light ("a" on pl. 1) were of great assistance for the knowledge of the general character of Hittite architecture. What we saw was the eastern half of several small rooms located on the edge of the large plateau of the Boyuk-Kale and supported by fortress walls (pl. 6). While the foundation of the walls of the rooms consists of quarry

stones, bound with loam, the walls themselves, about 1 meter thick, were once constructed of strong wooden joists or panels, with sun-dried bricks in single files. When fire destroyed the building, the woodwork vanished, its space being filled with débris and rubble ("b" on pl. 6), while the brickwork was burnt red, so that the walls are still about 1 meter above the ground ("a" on pl. 6). In one of these rooms, shoved into those parts of the wall from which the woodwork was burnt out, cuneiform tablets of the archives are said to have been found. The latter may have been originally preserved either in the basement or in the upper story.

The nature of the building to which the archive rooms belonged, whether palace or temple, can not be determined until further excavating is done. It extends far eastward over the plateau of the acropolis and has left remnants on the surface as well as under ground.

More definite details can be obtained about the site of the second archive which Makridy Bey discovered in the spring of 1907 before our arrival. A detailed account of the circumstances under which the cuneiform tablets were discovered and a discussion of the question as to how they came to this place is discussed by Winckler. In our opinion the archive remains were lying at the east side of the large building which has been taken for a palace. After a thorough examination by Krencker it was shown to have been a colossal temple. It was surrounded on all sides by paved streets, and close by, as at the Egyptian temples and old Cretan palaces, stood the vaults or magazines, narrow structures in regular arrangement, which, though once destroyed by fire, still contain the complete number, though in broken condition, of the vessels for receiving the revenues in kind of the temple. In some of the rooms of the eastern magazine ("b" on pl. 7) the tablets were found between the foundation walls. The mode of building the magazines was the same as that of the archives on the Boyuk-Kale, walls of panel work and sun-dried bricks upon stone foundations, only that here the walls entirely disappeared.

The temple itself was built in the same or a similar manner, only more solidly; the thick walls had a socle, about a meter high, of large blocks above the foundation. Hence after the destruction of the upper part by fire, enough remained of the stone socle to determine the ground plan of the entire building. This exhibits in general the character of the Mediterranean temple, but is substantially different from the temple plans of Mesopotamia, Egypt, and North Syria. It represents a quadrangular court; on the south it is accessible by a peculiar portal, and on the north side is a pillared hall; behind, in the midst of a group of rooms, there is a space, peculiar by its situation and its windows, which reach down to the socle, and in it, at the north wall, there is a large pedestal ("a" to

ROOMS ON THE BOYUK-KALE IN WHICH THE FIRST EARLIER CLAY TABLET ARCHIVES WERE DISCOVERED.

VIEW OF THE GREAT TEMPLE (*a*) FROM THE SOUTHEAST, AND OF THE EAST MAGAZINE (*b*).

ADYTUM, OR SACRED CHAMBER, OF THE GREAT TEMPLE. *a*. PEDESTAL FOR THE IDOL. *b-e*. WINDOW SILLS. *f*. THRESHOLD OF PORTAL TO NEXT ROOM.

JENIDSCHE-KALE CITADEL IN THE CENTER OF BOGHAZ-KEUI.

"e" on pl. 8), doubtless for the statue of the god who was here venerated. Winckler surmises that it was the god Teshub who once dwelt in this principal temple of Chatti.

The general arrangement of the temple was typical. Kohl proved the existence of, and then excavated, three other buildings of the same kind in the ancient city area—in the upper city. They are located, like the large one, upon natural terraces. A fifth building, close to the structure at the east gate, where in 1906 some tentative digging was done, exhibits an entirely different plan. It seems to have been a palace. The latter, like the four temples, exhibits peculiar elements within the type of old oriental architecture and is specifically North Hittite. We have thus gained a clear conception of the manner of building characteristic of the interior of Asia Minor in the second millenium B. C.

The importance of the site of the city has been pointed out by Winckler. The area, inclosed by fortress walls, is situated on the declivity of a mountain and at its foot. Its view is grander and more impressive than would appear from Humann's excellent chart of 1882, by reason of its wide expanse, its terrace-shaped construction, the great difference in height between the more level lower city and the more rolling upper city, and, finally, on account of the projecting summits and rocks, some of which were specially adapted for citadels. The city must have once presented a view similar to the Syrian fortress in Egyptian pictures. Kohl, with the surveying board, has made a new, careful, and accurate plan of Boghaz-Keui (pl. 9).

The general plan of the city, as well as the walls with their towers and gates, which no doubt belong to the same period as the temples and the palace, are on a grander scale than was to be expected from former accounts. The part of the walls constructed of large stones recalls in its technique the fortifications of the citadels of Mycenæ, which belong to about the same period, though not exactly identical with it. The principal wall of Boghaz-Keui stood upon a mighty earthern rampart, whose slope was plastered with stones. A similar construction is observed in Senjirli, North Syria. The wall averaged 5 meters in thickness, in places 8 meters, and consisted of a high stone socle or basement, of which some remnants remain; and upon this rose, according to authentic vestiges, a structure of wood and sun-dried bricks. The towers projected beyond the wall and were mostly in close proximity to one another.

In front of this principal wall, upon the slope of the rampart, stood another weaker wall, likewise provided with towers. Such a double wall also protected Senjirli, in North Syria, though it was

constructed after another scheme, and similar fortifications are now brought to light in Babylon and Asshur.

The so-called sally ports of Boghaz-Keui were very strong. They were narrow but high passages, vaulted with corbel, which led at some places through the rampart and were in parts 72 meters long. They were probably constructed for purposes of defense and served as sally gates.

The part of the wall most exposed to attack, in the south of the city, was more closely examined. The tower that stood in the center, on the highest point of the wall, was built as a gate tower whose entrance, both within and without, was flanked with sphinxes; fragments of the best preserved of these are now in Constantinople. At both ends of the front wall of attack, steep stone steps led from the ground through the plaster of the slope of the high wall to the end tower of the front wall.

Finally, as regards the city gates, we completed the uncovering of the south and east gates, which was begun by Makridy Bey in 1906, and excavated the two west gates, which were close together. At the lower west gate was found the tablet of Armuanta mentioned above. Each of the towers was flanked by a gate. The plan of the gates is very simple, including a chamber about the same width as the wall, which could be closed on either side. The framings of the openings consisted of large stones, constructed on the same principle as the roofing of the sally ports of a high elliptical corbel vault, but below it had colossal posts surmounted by two or three stones which gradually projected and inclosed the elliptical curve. While at the south gate (pl. 3) both posts are decorated with large lions on the outside, at the east gate (pl. 10) only the inside of the left post bears a sculpture, probably representing a young warrior in life size, who, like an Egyptian king, is clad only with apron and helmet, standing in the usual posture—the left hand balled, while in the right he holds a magnificent battle-ax. Unfortunately, there is no inscription attached to the figure, though it doubtless represents a Hittite king, either Subbiluliuma or Hattusil, or some other one who might have erected the walls and gates of Chatti. This royal figure and the lions at the east gate are, from an art standpoint, the finest and most important sculptures of the old Hittites so far known. European museums should at least procure plaster casts of them.

EAST GATE, FROM WITHIN.

MALARIA IN GREECE.[a]

By Ronald Ross, F. R. S., C. B.,
Professor of Tropical Medicine, University of Liverpool.
[Professor Osler, M. D., F. R. S., in the chair.]

Professor Osler and Gentlemen, I consider myself extremely fortunate in being able to introduce the subject of malaria in Greece to my countrymen, through such a very appropriate avenue as the Oxford Medical Society. I was actually considering how the introduction might best be effected when I received the invitation from your secretary to address you to-night. For where could anyone who wishes to discourse of Greece do so much better than in Oxford—herself the daughter of Greece, who has borne through the ages the torch first fired in that divine country? And, since my subject is Æsculapian, what audience could I find fitter than yourselves? But my luck does not end here; for in you, Mr. President, I have chanced upon the fittest of all presidents, eminent alike in science and in the humanities, to both of which my theme appeals. Further, when I first opened my beggar's wallet for subscriptions in aid of the cause which I have to advocate to-night, it was yourself who contributed the first dole—a goodly number of solid drachmæ, in aid of Greece. The omens are therefore propitious, and if I fail it will be the fault of myself rather than of fortune.

First let the Muse explain (she is sorry that she can not do it in hexameters) how it came that so humble an advocate as myself was selected for so great a client. Early in the year I was asked by a British company which owns certain large tracts of land in Greece to go there, in order to advise as to the best means of reducing the malaria which for a long time had been persecuting the company's employees. I arrived in Greece toward the end of last May, and there, sure enough, found Andromeda in tears, awaiting the onslaught of the fell monster which was just then preparing to arise (metaphorically speaking) from his long winter sleep in order to

[a] An address delivered to the Oxford Medical Society on November 29, 1906. Reprinted by permission from the Journal of Tropical Medicine, London, November 15, 1906.

devour her. After inspecting the latter, instead of slaying him outright, I determined, more wisely than heroically, to retire for assistance, and I am here to-night in furtherance of that intention.

Now let me begin by describing exactly my own experiences in Greece. As everyone knows, the country consists principally of a mass of mountains with small valleys between them here and there and many straits and inlets of the sea. In fact, the configuration is very like that of the Highlands of Scotland. The scenery does not possess the great variety of color caused by the light and shade of the humid atmosphere of the Highlands; it is brightly but uniformly colored. On the other hand, its comparative aridity is compensated for by a singular beauty and variety of contour, which are not excelled in the Alps or even in the Himalayas. High enough to retain for most of the months of the year an exquisite lacing of snow, the mountains, though barren and stony, make a long vista of outlines against the very lovely sky. I have never seen a sky equal to that of Greece. In the Tropics a yellow light is reflected from the burning ground upon the lower strata of the air, and only the zenith is blue; but in Greece the azure extends almost down to the horizon, except for a narrow margin of brilliant silvery or pearly light. After sunset the sky seemed to me to possess, not the deep night blue of the Tropics, but a wonderful purple tint of its own, in which the "new-bathed stars" shine with a brilliance not exceeded even in the desert. At midday the almost tropical glare of the sun on the chalky soil is relieved by the dark shades of the plane trees and the classical cypresses and the bright green of the vines. It has been my fortune to see many beautiful countries, but I think that Greece and Britain hold the palm.

The particular valley which I was called upon to visit was that of Lake Kopais, in Bœotia. After leaving Athens, the comfortable train winds along between Mount Pentelikon on the south and Mount Parnes on the north. Then, passing across the eastern spurs of Parnes, in full sight of the Island of Euboia and its strait on the right, it enters the Valley of Thebes. Traversing this it goes through the defile of the Sphingion (where the Sphinx used to waylay travelers with her riddles) and emerges on the Kopaik Plain. This is a large area about 6 miles broad and 12 miles long, the long axis pointing west and east. On the east the plain is bounded by the Mountain of the Sphinx, which seems from certain points of view to have the shape of a woman's figure reclined along its crest. Along the whole of the south side runs the beautiful range of Helikon, the Mountain of the Muses. The birthplace of Hesiod is in one of its valleys; and near one of the summits there is the famous fountain of Hippokrene, where the winged horse, Pegasus, took flight for heaven, owing, it is said, to some annoyance from the literary critics of the day. At the

western extremity of the plain rises the magnificent mass of Mount Parnassus, the Mountain of Apollo, with its summits clad in dazzling snow. But to resume. The Kopaik Plain itself is almost absolutely flat right up to the feet of the hills which bound it, being, indeed, the dried bed of a lake. In ancient days, according to the interesting writings of Dr. J. G. Frazer, of Cambridge, this lake was a large sheet of water in the winter, and in the summer a series of marshes overgrown with sedge, with rivers winding through them and patches of dry land between. The lake was drained in very remote times by the people of Orchomenos, a town upon its banks, and the remains of the drainage works are still visible. The water enters from numbers of small rivers and streams gushing out of the surrounding mountains and naturally escapes, singularly enough, into great caverns, of which there are many, called "katavothræ." In the Middle Ages the drainage works appeared to have been allowed to fall out of repair, but recently a French company resumed the task, and still more recently the work was taken up by the British company, the Lake Kopais Company, which asked me to study the malaria for them. The whole bed of the ancient lake is now a great plain covered with crops of all kinds, which repay the cost of the engineering works. The water is at present discharged through adjacent valleys into the sea.

It was here that the malaria was so troublesome. The Lake Kopais Company has many hundreds of employees and tenants, who were constantly being attacked, although most of them were natives of Greece. It had not been found possible to keep accurate statistics of the annual number of cases; so that my first care was to make an estimate for myself of the amount of malaria present. This can be done with a fair degree of accuracy, without the help of statistics, in two ways—by ascertaining the proportion of people which, first, have the parasites of malaria in their blood, and, secondly, possess enlarged spleens. The first method was much used in India by Stephens and Christophers, who called the ratio of infected persons to the total population the endemic index. To obtain an absolutely correct figure by this means we must make an exhaustive microscopical examination of the blood of every person in the area under consideration; but this would be too laborious for practical purposes; and we must consequently content ourselves with an approximate valuation obtained by examining only a part of the local population. As shown by these observers, and by Professor Koch, it is especially the native children in a malarious locality who have the parasites in detectable numbers—the older people becoming comparatively immune. The blood of a number of unselected children is therefore carefully searched for the parasites, and the ratio so obtained is recorded as the approximate endemic index. For exact work a large number of children must be

examined, as otherwise the margin of error, as shown by Poisson's formula, will be very considerable. For example, if 50 children be examined and 25 of them be found to contain parasites the error will be no less than 20 per cent; so that the approximate endemic index will not be 50 per cent, as a hasty observer may think, but anything between 30 per cent and 70 per cent. This fact is worth recalling, because it has been much overlooked in recent work on the subject, and because it shows how laborious the method really is. The second method, that of examining children for enlargement of the spleen, a thing which can be done in a minute, is much easier and fairly trustworthy, provided that no other cause for splenomegaly is present.

With the valuable assistance of Doctor Kardamatis, general secretary of the Grecian Antimalaria Society, and of Mr. D. Steele, manager of the Lake Kopais Company, in Greece, I was able to use both methods. The company's houses are on the southern border of the plain, close to the site of the ancient Haliartos, where the Spartan Lysander was defeated by the Thebans, 395 B. C., and to the reputed grave of Alkmene, the mother of Hercules. The houses are built just where the slopes of Helikon begin to rise from the plain; so that they were obviously not too highly situated to be affected by the malaria. On examining 57 of the employees, most of whom were Greeks, we found an enlargement of the spleen in 14 and the parasites in 9. But 5 of those that had parasites had no enlargement of the spleen, and must be added to the infected list, which therefore amounts to 19 out of the 57, or one-third. The majority of these people were adults, and many had come from other localities, so that the figures are not useful for statistics.

Our next care was to examine the people in some of the neighboring villages. Out on the plain, about a mile or more from the company's houses, there is the village of Moulki, containing some 350 inhabitants. The houses are closely clustered together, with very irregular and elementary lanes between them. Going to the village inn close to the school, we set to work and examined 80 persons, mostly children; first by palpating them for enlargement of the spleen, and secondly, by making dried films of their blood for future microscopical inquiry. The scene was most interesting. Seated under a large tree, with the village priest as our patron and protector, we pricked and palpated the little ones, one by one. I never saw pluckier children. Scarcely one of them even winced at the vivisection. Nearly all of them were very intelligent, and many good looking; but, alas! most of them were far from well, and some looked miserably ill, emaciated and anæmic. The cause was speedily revealed. Out of 62 of the children between the ages of 5 months and 14 years, no less than 35 were found to have enlarged spleens; and as no other cause of endemic splenomegaly, such as kala-azar, could be ascertained to be present in

the locality, we could attribute the enlargement in these children only to malaria. This diagnosis has been fully confirmed by subsequent examinations of the blood films, which showed that the parasites existed in at least 17 of the 62 children at the time when the films were made. Of these, 5 had an appreciable enlargement of the spleen, so that this number must be added to the number of spleen cases in order to arrive at the total yielding evidences of infection. Hence, out of the total 62 children, no less than 40 were certainly infected—a ratio of them of 64.5 per cent. This is, of course, the lower limit of the ratio, because it is quite possible, and indeed very likely, that the parasites were overlooked in some of the films. Such a ratio was unexpectedly high for any European country, and is almost equal to any that has been found in Indian or African children.

I may add that in many of the children the splenic tumor was very great, reaching almost to the crest of the ilium. This is important, in view of statements recently made in India to the effect that great splenic tumor is probably due to kala-azar, rather than to malaria. The former disease is apparently not present in Greece, the *Leishmania donovani* parasite never having been discovered there. Moreover, the Grecian cases were markedly different from the cases of kala-azar studied by me in Assam, in 1898, for the purposes of an official report. In not a single one of the former did we note any enlargement of the liver, so commonly seen in kala-azar; there was not the constant fever of kala-azar, the expression of the face was the unconcerned expression of malaria rather than the hopeless look of the deadly eastern disease; and lastly, the death rate was far too small for the latter. Nevertheless, the splenic enlargement in a few of these cases of pure malaria was, I think, as great as anything I saw in kala-azar. Of course, many of the children were shockingly anæmic and emaciated—not in any way, I was informed, from lack of food, nor, apparently, from the great prevalence of other diseases. The work was clearly that of the spirit of the marsh.

The next thing to do was to find the source of the malaria, or rather its carrying agents, the local Anophelines. As I have said, the Kopaik Plain is now drained and cultivated over its whole extent; but numerous small streams enter it from the surrounding hills, traverse it, and discharge into the main channels of drainage. These streams are swollen torrents in the winter, but in the summer often become trickles of water with occasional marshy borders here and there. Several such streams enter the basin near Moulki; but at that season (May to June) we could find no Anopheline larvæ in them, though some have been found subsequently, as we conjectured would happen with the advance of the dry season. But in addition to these streamlets there exists a long series of shallow pools suitable for the larvæ in the "borrow pits" made by the engineers who constructed

the railway embankment across the plain. Sure enough, in some of these pits close to Moulki we found the peccant insects, the larvæ of *Myzomyia maculipennis*, a known carrier of malaria. These gnats, rising from the pools, pour into the village and into neighboring houses, such as those of the company; become infected by biting the numerous infected children; and then infect any healthy persons whom they may subsequently bite. The old drama, now so well known, was obviously being played out before our eyes.

After having dealt with Moulki we examined the conditions at another village of about 575 inhabitants, situated several hundred feet high on the hills south of the company's houses, and called Mazi. Out of 40 school children, we found enlargement of the spleen in 13, and the parasites of malaria in 16. Of those that showed the parasite, 7 had no enlarged spleen; so that we must add them to our total of infected children, giving 20 infected out of a total of 40 examined; that is, one-half. This is a large proportion, and we expected to find some breeding pools of Anophelines close at hand. In this, however, we failed; though we saw some lime pits which we thought might become suitable for the larvæ at a later season. But, nevertheless, there was no difficulty in explaining the malaria at Mazi, since we learned that every year nearly the whole population descends to the plain for the harvesting in the month of August (the most malarious month) and bivouacs there for days or weeks. Doubtless the people of Mazi become infected on these occasions, though I suspect that breeding pools will be found close to the village by more extensive search.

My time being very limited, we could make only hasty studies at other spots. Across the plain lies the village of Skripou, on the site of the ancient Orchomenos. Here we found splenic enlargement in exactly half of 40 school children examined; but had no time to take blood films. The village is evidently intensely malarious. We had time to look for mosquito larvæ only in one spot, the beautiful Fountain of the Graces, which gushes out of the mountain and spreads in a small marsh near at hand. Here, again, we found the shameless insects desecrating the divine spot. What must have happened when the Graces bathed there I can not say. We saw only washerwomen and geese.

Thus on the borders of the Kopaik Plain we had examined 142 children and had found certain evidence of malaria in no less than 80, or 57 per cent, a very high malaria rate. But we soon obtained evidence that the disease is not confined to this low-lying area. Livadhia is a beautiful little town of 6,250 inhabitants, situated 540 feet up the spurs of Helicon, some miles beyond the western end of the plain and facing Mount Parnassus. It begins at the romantic gorge where was the Oracle of Trophonios in former days, and where

the two springs of Lethe and Mnemosyne—Forgetfulness and Memory—now flow out of the rock. Notwithstanding the height of the situation and the absence of any apparent marshes close at hand, we found enlargement of spleen in 16 out of 100 school children here. The infection is probably obtained in lower areas outside the town; but we had no time to make any search for the Anophelines. We spent some hours also at Thebes itself. This famous place, which used to contain 40,000 inhabitants, now contains only 4,780. Situated on a rocky eminence in the midst of a large plain, the historic Kadmeia, it is considered to be fairly healthy, and indeed we found enlargement of the spleen in only one child out of 50 examined, and failed in obtaining any larvæ of Anophelines in several small pools round the base of the renowned citadel. Such researches carried out on the spot where lived Pindar and Epaminondas, where Theban, Athenian, and Spartan had frequently mingled in battle, and where angry Alexander wreaked his vengeance, were "of the age." I am not certain whether the little wriggler of the puddles had not been a worse enemy to Thebes than was the great conqueror. One remains; the other has passed away for ages. If Diogenes had possessed our present knowledge, he might have made a still more caustic reply to his powerful visitor.

Thus, altogether, out of 292 unselected children examined by us in five different places, we found unmistakable evidence of malaria in 97, or one-third. In addition to the children, we examined 18 adults at Moulki. As is now well known, the adult natives of a malarious locality become comparatively immune, their spleens returning to the normal size, and the parasites becoming extremely scarce in their blood. Nevertheless, we found signs of malaria in 4 of these adults, but, of course, such figures are not useful for estimating the endemic index. Including all, we found certain evidence of malaria in 120 out of 367 persons, or 32 per cent. The figures for the children, however, give a reliable and high malaria rate, especially when it is remembered that they were collected at the beginning of the summer, before the annual malaria season had commenced. Later in the year the endemic index would certainly have been still higher. If, moreover, we had examined the blood of the 200 children dealt with at Orchomenos, Livadhia, and Thebes, we should certainly have been able to add many other cases of infection to our list; while lastly we should remember that in all cases of malaria the parasites frequently become temporarily too few for detection by the microscope. Our total estimate of 33.2 per cent infected children must therefore be much below the maximum ratio, and may be looked upon as a minimum ratio. The statistical corrections by Poisson's formula works out at 7.7 per cent, so that we have finally for the five localities, Moulki, Mazi, Orchomenos, Livadhia, and Thebes, a minimum child-

malaria rate of between 25.5 per cent and 40.9 per cent. The truth is probably that at Moulki and Orchomenos all the children are really infected in the autumn.

With regard to the number of breeding places of Anophelines we found them only in two small pools, one at Moulki and one at Orchomenos; and the former of these was immediately drained away by Mr. Steele, of the Lake Kopais Company. The season, however, was early, and our search far from exhaustive. Many more pools will, of course, be found; but, nevertheless, I infer that the amount of breeding surface per square mile of country is extremely small, so that antipropagation measures ought to be correspondingly cheap.

Such were the results of my own observations; and I will now give briefly some figures which I obtained for the whole of Greece. Within the last year or two there has been founded at Athens an admirable malaria society for the study of such questions. It is under the patronage of His Majesty the King of Greece, and consists of many enthusiastic members. One of these is my friend Doctor Savas, professor of hygiene at the University of Athens and physician to the King of Greece, and the general secretary is my friend Doctor Kardamatis, who gave me so much assistance at Lake Kopais. I can testify to the complete knowledge of the subject possessed by both of these gentlemen—whom I mention more particularly than their colleagues, because I was brought more especially into contact with them—to their zeal in the cause, and to their philosophic grasp of the importance of the malaria question for their country. From them I obtained the following approximate figures for the whole of Greece:

Population of Greece	2,433,806
Average annual number of cases of malaria	250,000
Average annual number of deaths from malaria	1,760
Number of cases of malaria during 1905	960,048
Number of deaths from malaria during 1905	5,916

These figures are, I think, as sound as any that can be collected from statistics. Malaria is a very difficult disease to deal with in this way, because it does not consist of a single severe attack demanding immediate medical assistance, but rather of a series of comparatively slight attacks extending over a period of years, and, moreover, occurring principally in young children. Many cases do not find their way into the returns at all, while, on the other hand, relapses must be frequently entered as fresh infections. As for the death-rate, comparatively few cases die simply of malaria, but many are carried off by intercurrent pneumonia or diarrhea, or perish gradually from anæmia, under which headings the mortality is often recorded. The figures given above, however, agree entirely with my own estimate of the endemic index round Lake Kopais; and I believe that if similar

methods could be used all over Greece—if all the children in the country could be examined—it would be found that an extremely large proportion of them are constantly infected. Last year was a very bad year, with a recorded death rate of 2.4 per thousand of the population. Nor is the malaria of a benign type in Greece. On the contrary, I was informed by all the gentlemen mentioned above, and also by a number of medical men whom I met at Thebes and Livadhia, that pernicious attacks are very common, and that the most serious form, that of blackwater fever, is extremely common. Such facts are recorded also in the writings of Kardamatis, Savas, and other able Greek observers. The disease is therefore extremely, if not shockingly, rife in the country—much more so even than in Italy. Doctor Savas told me that from some statistics which he had studied the number of cases and deaths in Greece are half again as numerous as in Italy for equal numbers of people. All species of the parasites are to be found in Greece. In our own studies the mild tertian parasite occurred most frequently, the so-called malignant species next commonly, and the quartan least of all—but not rarely. As I have said blackwater fever, the worst form of malaria, has been very common in Greece. Regarding the species of Anophelines, which carry malaria in the country, Doctor Savas told me that out of 1,839 of these insects 1,778 were found to be *Anopheles maculipennis*, 21 to be *Anopheles bifurcatus*, and 20 to be *Pyretophorus superpictus*, all well-known agents of the disease.

Now, what must be the effect of this ubiquitous and everlasting incubus of disease on the people of modern Greece? Remember that the malady is essentially one of infancy among the native population. Infecting the child one or two years after birth, it persecutes him until puberty with a long succession of febrile attacks, accompanied by much splenomegaly and anæmia. Imagine the effect it would produce upon our own children here in Britain. It is true that our children suffer from many complaints—scarlatina, measles, whooping cough—but these are of brief duration and transient. But now add to these, in imagination, a malady which lasts for years and may sometimes attack every child in a village. What would be the effect upon our population, especially our rural population—upon their numbers, and upon the health and vigor of the survivors? It must be enormous in Greece. People often seem to think that such a plague strengthens a race by killing off the weaker individuals; but this view rests upon the unproven assumption that it is really the weaker children which can not survive. On the contrary, experience seems to show that it is the stronger blood which suffers most—the fair northern blood which nature attempts constantly to pour into the southern lands. If this be true, the effect of malaria will be

constantly to resist the invigorating influx which nature has provided; and there are many facts in the history of India, Italy, and Africa which could be brought forward in support of this hypothesis.

We now come face to face with that profoundly interesting subject, the political, economical, and historical significance of this great disease. We know that malaria must have existed in Greece ever since the time of Hippocrates, about 400 B. C. What effect has it had on the life of the country? In prehistoric times Greece was certainly peopled by successive waves of Aryan invaders from the north—probably a fair-haired people—who made it what it became, who conquered Persia and Egypt, and who created the sciences, arts, and philosophies which we are only developing further to-day. That race reached its climax of development at the time of Pericles. Those great and beautiful valleys were thickly peopled by a civilization which in some ways has not since been excelled. Everywhere there were cities, temples, oracles, arts, philosophies, and a population vigorous and well trained in arms. Lake Kopais, now almost deserted, was surrounded by towns whose massive works remain to this day. Suddenly, however, a blight fell over all. Was it due to internecine conflict or to foreign conquest? Scarcely: for history shows that war burns and ravages, but does not annihilate. Thebes was thrice destroyed, but thrice rebuilt. Or was it due to some cause, entering furtively and gradually sapping away the energies of the race by attacking the rural population, by slaying the newborn infant, by seizing the rising generation, and especially by killing out the fair-haired descendant of the original settlers, leaving behind chiefly the more immunized and darker children of their captives, won by the sword from Asia and Africa?

Those who have read Dr. W. North's fascinating book on "Roman Fever" (Sampson Low, Marston & Co., 1896) will remember the suggestion that the depopulation of the Campagna was due to the sudden introduction of malaria by the mercenaries of Sylla and Marius, and so recently as 1866, as we know from the works of Doctor Davidson, of Edinburgh, malaria entered and devastated the islands of Mauritius and Reunion, either the mosquito or the parasite having been then brought in from without. Similarly, could it not have been introduced into Greece about the time of Hippocrates by the numerous Asiatic and African slaves taken by the conquerors? Supposing, as is probable, that the Anophelines were already present, all that was required to light the conflagration was the entry of infected persons. Once started, the disease would spread by internal intercourse from valley to valley, would smolder here and blaze there, and would, I think, gradually eat out the high strain of the northern blood.

I can not imagine Lake Kopais, in its present highly malarious condition, to have been thickly peopled by a vigorous race; nor, on looking at those wonderful figured tombstones at Athens, can I imagine that the healthy and powerful people represented upon them could have ever passed through the anæmic and splenomegalous infancy (to coin a word) caused by widespread malaria. Well, I venture only to suggest the hypothesis, and must leave it to scholars for confirmation or rejection. Of one thing I am confident, that causes such as malaria, dysentery, and intestinal entozoa must have modified history to a much greater extent than we conceive. Our historians and economists do not seem even to have considered the matter. It is true that they speak of epidemic diseases, but the epidemic diseases are really those of the greatest importance.

The same cause works the same evil in modern Greece. Though the country has been freed from the Turks for seventy years, and enjoys what is considered to be (though personally I doubt it) the best form of government, yet its population has not increased very much. Athens has about 130,000 inhabitants, and Patras, the next largest city, about 40,000; and the other towns are scarcely more than large villages. The rural areas contain small and poor, but not destitute, hamlets, but what strikes one most in them is the absence of villas and of large hotels. Few of the wealthier people seem to live in the country. A gentleman of Athens told me that he bought a shooting box, but that he was attacked by malaria when he went to stay there. The inns are comparatively small and shabby, and not likely to be frequented by many modern tourists, and the methods of communication are primitive. This is very surprising, because one would think that such a country would be the Mecca of all the tourists of Europe and America, who would pour their millions of pounds into it, just as they do into Switzerland. But, of course, the reputation of unhealthiness possessed by many of the rural tracts is fatal; the tourist thinks twice about going to them, and the innkeeper hesitates about spending his capital in a locality where he and his children may expect to be frequently ill.

The whole life of Greece must suffer from this weight, which crushes its rural energies. Where the children suffer so much, how can the country create that fresh blood which keeps a nation young? But for a hamlet here and there, those famous valleys are deserted. I saw from a spur of Helikon the sun setting upon Parnassus, Apollo sinking, as he was wont to do, toward his own fane at Delphi, and pouring a flood of light over the great Kopaik Plain. But it seemed that he was the only inhabitant of it. There was nothing there. "Who," said a rich Greek to me, "would think of going to live in such a place as that?" I doubt much whether it is the Turk who has done all this. I think it is very largely the malaria.

Now, regarding the remedy. Science has, of course, shown absolutely that the disease is carried by gnats, and, in doing so, has indicated several methods of prevention. First, there is the method of excluding gnats by the careful use of mosquito nets and wire-gauze screens to the windows—useful for the houses of the rich, but too costly and troublesome for the poor. Then, there is the method of Koch, the cinchonization of all the patients, by which they themselves are benefited, while the gnats do not become infected and therefore do not spread the parasites; but this implies rigorous dosing with quinine for months—a thing which patients and the mothers of children will not submit to. But the method which I first suggested and elaborated in 1899, namely, the reduction of mosquitoes, is the one which I prefer, and the one which, after seeing the conditions in Greece, I prefer more than ever. It is, of course, the old Roman plan of drainage against malaria, with this important difference, that we are now no longer compelled to drain the whole surface of a malarious area, but only those small pools in which the Anophelines breed. This method has the immense advantage that it can be carried out by local authorities without troubling the people; while in the end it is sure to be more economical and lasting in its effects than other methods which, I think, are apt to cause waste both of money and effort. To Greece it is most especially applicable. There, the rainy season is the winter, when the mosquitoes do not breed; so that in the arid summer they can find only very few suitable breeding pools. So much the easier and cheaper will it be to treat these. They can be rendered uninhabitable for the larvæ by drainage, by filling up, by deepening, by dragging the weeds, and in the last resort by periodic oiling. Where carried out with intelligence and loyalty, as in Habana, the federated Malay States, and Ismailia, the work has proved comparatively easy and cheap, while the results (now so well known) have been of the most brilliant kind. I think that Greece, owing to the scarcity of surface water suitable for the larvæ in the summer, will be easier to deal with than any of these places—easier even than Ismailia, with its irrigation system. It will be strange indeed if so intelligent a nation can not carry out such simple measures in order to rid itself of a plague which has oppressed it for ages.

The Grecian Malaria Society has commenced the work with energy. It has investigated local conditions; has issued numerous tracts to the people; has urged railway companies to screen stations, and Government to undertake drainage. Doctor Savas suggests government regulation of the sale of quinine in order to improve and cheapen the drug—a most necessary item. At Athens, where malaria exists only along the bed of the Ilissos, the stream has been "trained" in many places. Presently I hope we shall see a survey made of the malaria and the local breeding places in the whole of Greece, pre-

paratory to a general onslaught on the foe. When I was in Athens I had the pleasure of speaking to M. Theotakis, the premier, and Mr. Boufidis, the president of the chamber, and am sure that the Government will do its best to support the campaign. But the society will have to fight many enemies, chief among which will be the incredulity and indifference of the public. I have therefore suggested that we in Britain may help it by doing something to show our support of it. The Liverpool School of Tropical Medicine has accordingly offered its assistance, which has been accepted by the King of Greece; and under the patronage of Her Royal Highness Princess Christian, we have opened a list of supporters, which now includes many eminent names, beginning with those of the Greek minister in London, the British minister in Athens, the presidents of the Royal Society and the British Academy, the Royal College of Physicians, and many Greeks residing in Britain. It often happens that a little foreign support will do more to encourage a cause than much local effort can do.

When matters are in proper train, every year will see the removal of a number of the little marshes which are so injurious to the country—every year will see a decrease in the malaria. I venture to say with confidence that, give us but the necessary means—and we do not require much—there is no country in the world from which we could not extirpate the disease. Hitherto we have contented ourselves with diminishing it in isolated towns. Let us now deal with whole nations. Remember that it has actually been banished from Great Britain, almost by unconscious agencies. We have only to imitate those agencies consciously. What a triumph it will be for that great science, of which all of us are the humble votaries, if she can wipe out this miasm, this defilement, from an entire country. I will not hesitate—such is our ambition. And that country is Greece.

I asked a Greek friend why his countrymen did not restore the Parthenon. He replied it was because they were unwilling to touch the sacred ruins without the assent of the whole world, to whom they belonged. So also Greece belongs to the whole world. We all share in her troubles and should do our best to relieve them. Many years have passed since Byron gave his life for Greece. He attributed her misfortunes to loss of liberty. Perhaps so; but I think that an enemy more inveterate than the Turk has also destroyed her. Not least among the nations, Britain has studied to help her against her human enemies. Should we not help her now against the more potent enemy which we have discovered. That science which, more than two thousand years ago, she created is at our side urging us on. We have no doubt of the result—we need only to nerve the arm to strike.

Gentlemen, it was my good fortune to stand the other day at a spot from which can be seen within eyeshot the birthplaces of science, art, philosophy, the drama—of Europe, of our modern civilization. It was a great rock rising in the midst of a city built on a plain—not a boundless, uninteresting expanse, but a plain, defined as such by a cincture of beautiful mountains. I have known many of the loveliest scenes of this wonderful earth, but nothing altogether equal to the Attic plain. The rock was the Acropolis, and the setting sun flooded it with light. Upon it rose those ruins which are unsurpassable, unpaintable, and indescribable, because they were built, not only for themselves, but for the visions which surrounded them—the Propylæa, the Erechtheion, the Parthenon. And who was the god for whom that temple was built—which of all those gods, who are not dead as some imagine, but who live now and will live forever until, as the [illegible]rence, that dares forget the past"—who live because the[illegible]ce of a ing types of our own spirit? That goddess whose b[illegible]ligies were recorded on the pediments of the Parthenon, w[illegible] not from the common zygosis of nature, but full-armed fro[illegible] the head of Zeus, at the touch of fire and toil, who conquered the deep himself. Study her attributes, perceived and recorded in legend by the sages who lived before history was born, and we shall know her. Without human weakness she led Ulysses through the dangers of the deep, she gave Perseus the weapons with which he slew the monster of the deep, she destroyed the city of the deep, she made Athens triumph over the deep, and to-day has lifted man in a few centuries from the deep to heights unimagined before—science herself. The Parthenon was the temple of science. The great figure of science standing before it dominated the whole of Greece. At its gates, even, stood the figure of Hygeia, the science of health, whom we now invoke. Science is the goddess whom we serve, as did the ancient Athenians, because we know that she and she alone can save us from these elements of the deep which oppress us. We are her servants. We honor not the baser gods—the quack remedies, the sham philanthropies, the false knowledges, the mock philosophies, the whining pities, the lying politics which keep men down in the depths. We acknowledge only the intellect which sees the truth and smites the evil. Let us pray Pallas Athena to revisit the land where she was born.

CARL VON LINNÉ AS A GEOLOGIST.[a]

By A. G. Nathorst.

In the year 1759 Linné, in his suggestions as to what traveling naturalists should observe, says, among other things:

> Greeks resi[illegible] has commenced his journey and has become transport will [illegible] into a new world, he should consider it his duty to observe [illegible]elessly or at random, but so that nothing will escape his Wh[illegible] alert attention. In describing objects he must endeavor to [illegible] are so faithfully that he who reads the description must needs believe he [illegible] beholding the very things himself.

* * * * * * *

All his journeys had, however, been completed when the above-cited instructions were given, as his last journey, that to Skåne, was made in 1749. From this it may be concluded that his suggestions were based upon the experience gained in his own travels, and it is therefore interesting to read his detailed instructions concerning geological investigation. Since at that time geology did not exist as a separate science these precepts will be found partly in the eighth paragraph under the title "physics" and partly in the ninth paragraph under the title "concerning the mineral kingdom."

From the former of these paragraphs the following may be quoted:

> Rocks, especially stratified earth and stone, should be examined wherever possible; subterranean grottoes should also be explored, as the latter are liable to contain objects worthy of interest. These, as well as other places, should be examined for indications of the decrease of water or of the growth of land.

Paragraph 9, "concerning the mineral kingdom," is here given in its entirety:

> The common varieties of earth: Loam, clay, sand, gravel, and chalk, with the relative amounts and composition of each. The different kinds of stone: These, as a rule, vary in different localities and afford an important clue to the nature of the underlying rocks. The principal rocks: Sandstone, flint, slate, limestone, talc; agglomerations of stone, such as stalactites, bog ore, etc. Fossils, rare as well as common. Ores of various kinds with their valuable mineral inclusions.

[a] Translation, condensed, by permission, from Carl von Linné, Såsom Geolog. Af A. G. Nathorst. Med 2 taflor. Upsala, 1907. Almqvist & Wiksells Boktryckeri–A.-B.

The characteristics of the different kinds of rock (Lithogenesis) are to be carefully studied in order that sufficient observations may be made to explain the derivation of the rocks, and particularly the ores. Specimens of ore should be diligently collected and preserved.

Although these instructions were intended for travelers in foreign countries, it is quite evident that they were intended to apply with equal force to those who traveled within the mother country (Sweden), a necessity which Linné had emphasized in a special lecture delivered in 1741.

He says in this lecture—

Nowhere abroad have I found a region richer than our own country in the marvels of nature; none in which her masterpieces are so numerous or astonishing.

And in the instructions, part of which is quoted above, the traveling naturalist is expressly enjoined not to leave his own country—

until he has acquired a thorough knowledge of natural history and has scrutinized the various parts of his own country; in order that he may not, so to speak, cross the stream for water, and waste his money endeavoring to learn in a foreign country what he might have acquired at home, and for almost nothing.

In addition to what immediately concerns the mineral kingdom, the instructions contain precepts concerning notes and observations to be made within various other departments of science, geography and physics, botany and zoology, domestic economy, pathology, dietetics, etc., given for the purpose of illustrating his introductory statement that the naturalist "should observe everything."

This requirement is of particular value to the geologist, who must draw his conclusions of the past from present conditions, since the more familiar he is with nature as it now appears, the more clearly and correctly will he be enabled to interpret the happenings of remote ages. Under such circumstances it is but natural that Linné, preeminently a naturalist, who manifested an equal interest in every phase of nature, should have recorded his name as well in geological annals, although until recently this fact has not been justly recognized.[a]

At the period when Linné was pursuing his academic curriculum the differences of opinion as to the nature of the fossils to be found in rock strata, differences which had prevailed since the days of Aristotle, had been so far settled that the fossils were no longer considered as accidental formations, or freaks of nature, but were quite generally recognized as relics of animals and plants that had formerly existed on the earth. Another common view, however, and one which, in the eighteenth century, operated as a stumbling block in the devel-

[a] Recognized in Sweden for the first time by A. G. Nathorst, "Jordens Historia," pt. 1, pp. 36–43. Stockholm, 1888.

opment of geological science, was that fossils represented beings that had perished in the "deluge." Linné, however, did not share this opinion, and, as we shall find later, put himself on record more than once as opposed to it. It does not appear that he doubted the biblical version of the great flood, but that he believed it had taken place before the continents had reached their present magnitude. This view was advanced in his lecture on the growth of the habitable globe, an address delivered in 1743 at the conferring of the degrees of doctor of medicine at Upsala: * * *

* * * From all this I believe I may safely draw the conclusion that the portion of the land above the surface of the sea is yearly increasing; on the other hand, that it was formerly much smaller, and that in the beginning it was merely a tiny island, upon which, as though in concentrated form, was to be found everything that the all-bountiful Creator had destined to be of use to mankind. * * *

Is it credible that the Creator of the world should fill the earth with animals only to destroy them all shortly afterwards through a deluge, with the exception of a single pair of each species, preserved in the Ark? * * *

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Although Linné had entirely emancipated himself from the prevailing opinion as to the connection of the "deluge" with the formation of the soil and the stratified rocks, he, in common with his contemporaries, had no adequate conception of the enormous length of geological time. Otherwise he could not have fixed the time for the formation of the land at a period subsequent to that of the deluge. It should, however, be admitted that during his journey in Skåne the tremendous period representing the age of the earth may at least have dawned upon his mind. This journey was undertaken in 1749, or six years subsequent to his lecture on the growth of the habitable globe, wherefore the experience then gained could have had no possible influence on his discourse in 1743. Still later[a] Linné explained his position on this subject clearly and explicitly, as follows:

Nor should lithology be ungrateful to Linné. He was one of the first and one of the most prominent to call attention to the decrease of the water and the expansion of the continents, going back to the time of Paradise. He would even have believed the earth to be older than the Chinese believe it to be, had the Scriptures allowed it.

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Linné's idea that the growth of the continents occurred only subsequent to the "deluge" led him to quote, as proofs of the decrease of water, evidences from such widely separated periods as the Cambro-Silurian on the one hand and the Quaternary on the other. This error, which had already been committed by Swedenborg, was not an unnatural one for the time, and it must not be forgotten that the

[a] Afzelius, A., "Egenhändiga anteckningar af Carl Linnæus om sig sjelf med anmärkningar och tillägg," p. 213, Upsala, 1823.

writings in which Linné expressed his views on geology were, with the exception of the twelfth edition of the Systema Naturæ, published before 1760, and the majority even before 1750. By this time he was probably so engrossed in his botanical and zoological labors that he could devote but little time to "the mineral kingdom." * * *

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For the sake of brevity it may be advantageous to collect Linné's geological observations and remarks under the various subjects with which they deal. I shall commence with:

The Question of "Decrease of Water" or Growth of Land.

In his review of the Lapland journey we find the following observation from Helsingland:

> At several places on the road from Njutånger to Brinstad I saw a violet-colored clay which was used in fertilizing * * *. Between the inn at Iggsund and Hudiksvald I saw plenty of the same violet clay, a stratum of which could be seen in the ditches of the moor * * *. In this clay there were seen small, white, fairly perfect, smooth shells (*Tellina baltica*), but upon close examination the violet-colored part seemed to me to be composed of brown shells, such as abound on the seashore (*Mytilus edulis*). It is also my firm belief that all these dells and swamps formerly formed the sea bottom and that the top of the mountain was once a visible reef.

This quotation is of special interest, since it is the first instance in which Linné cites an observation of his own as proof of a former higher water level. That he was particularly interested also in the question of the "decrease of water" is evident also from his close connection with Anders Celsius, who, the year before (1731), had had a high-water mark cut in a rock in the vicinity of Gefle as a guide to posterity. In his speech on the growth of the habitable land (1743), Linné reverts to the following observation:

> The conchiferous earth common in Helsingland is exclusively composed of brownish pieces of a shell called "*Mytilus*." It is, however, a well-known fact that these shells exist in the sea, and not on dry land.

In the Œconomia Naturæ (1749) he says:

> The innumerable shells now lying many miles from the seashore, in the soil of Helsingland, never lived on dry land, but in water.

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In the description of his journey in Dalecarlia there is a very remarkable statement—discussed by myself in 1890—concerning a phenomenon that has only been satisfactorily explained within our own times. In his diary for July 20, 1734, Linné writes:

> When at Gröfvel Lake, Vala Mountain, we could see, on the east side of the lake, near Palm Peak, several horizontal ridges along the side of the peak high above the lake, ridges which were said to have been formed by the rising of the water immediately after the deluge.

There was no further reference to the subject, but Linné mentions the matter again in the lecture previously referred to:

In the mountains of Dalecarlia and Vala Mountain, where Palm Peak adjoins Gröfvel Lake, the eastern part of the mountain is grooved and polished, sure signs of wave action.

This observation was certainly remarkable, as Gröfvel Lake, situated on the border line between Dalecarlia and Norway, is 791 meters above sea level. * * *

Not until 1890 was the true explanation found. * * * The truth is that Gröfvel Lake lies where the inland ice—because of the fact that the gathering ground of the glacier lay to the east of the watershed, and because of the fact that the glacier moved toward the latter, i. e., from a lower to a higher level—dammed many lakes and river valleys and formed lakes, the existence of which has become known only by the old shore lines high up on the mountain sides. * * *

As is well known, the journey to the islands of Öland and Gotland was undertaken in 1741. His route took him from Stockholm, through Südermannia, Ostrogothia, and Smålamd, to the town of Kalmar, whence he sailed for the islands. * * *

It was in these islands of the Baltic that Linné was to find the most unmistakable traces of a former higher elevation of the water. He observed the raised beach on the eastern shore of Öland and how it was blotted out in places and could be recognized only by stone and gravel formations. On the northwestern side of the island he noticed how—

the sea was throwing up small dunes, about 20 yards wide and a few yards high, a short distance from the main beach, and composed mostly of large stones, here and there consolidated by an accumulation of sediment. It can thus be seen that the land is still increasing and that new beaches are constantly being formed.

From the northern point of Öland another instance may be quoted:

The Fields of Neptune is a good name for the stretch of land which extends along the coast for nearly a mile from Torp. It is about as wide as the range of an ordinary gunshot, and several such in length. This ground looked like the ordinary cultivated fields of Skåne and Upland, where there are numerous drainage ditches; indeed the likeness was so great that one might even be tempted to insist that only the plow could have created such an effect. But, upon close inspection, it was found to be composed almost entirely of finely ground flint gravel cast inland by the storms and waves of the sea. When the water retreated, the ground closely resembled a plowed field.

Although he does not state whether the ridges ran parallel with the coast, the description evidently refers to several terracelike beaches at various heights, such as Linné later described from Gotland. These "Fields of Neptune" are referred to in the Œconomia Naturæ (1749) as an example of places where the sea formerly raged. Pro-

fessor G. Holm, who has visited the place, confirms the truth of this observation.

On the island "Jungfrun," or, as it was formerly called, "Blåkulla," Linné also found evidence of former higher water levels. He says:

On the shore, at the foot of the rock, were deep cavities and oblong channels bored and hollowed out by the waves of the sea. Even on the highest rocks undulatory formations were found, showing that the sea had formerly raged there. Large blocks of polished stone had been thrown up in piles at a stone's throw from the shore, and even in the valleys between the highest mountains were similar stone piles completely overgrown with *Lichene crustacco leproso*, a sign that the waves did not spend their fury here yesterday.

But it was particularly on Gotland that Linné found an opportunity, on a larger scale, to observe shore formations of a time when the level of the water was higher than now. On the trip between Korpeklint and Lummelund he saw how—

the road, which was full of stone flakes, was constructed and repaired with small, round pebbles, which were lying around everywhere and were used instead of ordinary earth. These round pebbles, although lying so far up along the top of the ridge, testified to the fact that the sea had polished them and massed them together. One may imagine that when the sea laid the foundation of this land the ridge was at first a shoal, on the sides of which the slowly retreating water constantly threw up sand and gravel.

This ridge of which Linné speaks, and the origin of which he correctly explains, is of great geological interest. According to the government geologist, H. Hedström, it is a beach of the Ancylus Lake, at which period, as is well known, the Baltic Sea was an inland lake of enormous size, cut off from direct communication with the ocean.

But Linné was to find still greater evidences of the increase of land at Kapellshamn, in the northern part of the island, and at Hoburgen, in the southern.

"Coral strands" I call the beaches that were seen on the east side of Kapellshamn, as they were very wide and covered with white and gray blocks of stone. * * * This shore had a wavelike formation, like a furrowed field, with long, small, convex ridges running parallel with the harbor and growing higher and higher farther inland, so that the inner ridge was always a little higher than the one nearer the shore. They were all quite bare and entirely composed of blocks of coral, but those found farther inland gradually became covered with surface soil. Here we had the very clearest evidence of the annual growth of the land by means of these corals, or *Madrepora*, which can grow nowhere except in the depths of the sea, from whence they are cast up on the shore, thus increasing the mass of the land. * * *

* * * Still more remarkable is his description of the analogous ridges from the eastern coast of the island, near its southern point.

The annual increase of the land was here so obvious that we may say that we never saw more striking examples, particularly on the eastern shore where

the land begins to narrow, and before we came to the farm. The land, which was here slightly hilly, was like a plowed field toward the east, the furrows of which ran parallel with the shore. Each ridge was about 6 to 18 feet wide, and the side of it turned toward the sea was always the wider. On the shore itself we saw how these ridges are formed, namely, one each year, from the gravel thrown up by the sea. Close to the shore these ridges were seen quite plainly, but further inland they were more flattened out and more difficult to distinguish. From the shore we walked inland, making a careful count of all the ridges which we could see distinctly, in order not to miss a single year. We counted in all 77 of these ridges, of which the last was situated at least 500 yards from the sea, measuring by our steps. If we had had instruments so that we could have obtained careful measurements of the distance of the innermost ridge from the sea and its height above sea level, we should thus have been able to ascertain how much the sea had retreated in those seventy-seven years. Such a yearly increase of the land I have never before noticed in all my travels. However, it seems somewhat strange to me that the seventy-seventh ridge should lie so far from the sea that from it the western shore of the island could be seen directed overland. From this fact, however, it may be concluded that this point is much younger than has been generally supposed. Indeed it is possible that the sea, having established such clear landmarks between these ridges, should in this way mark off a certain number of years, particularly as the ridges are nowhere broken nor crowded together. It would be desirable if some surveyor who happens to come this way would take notice of this.

Probably no investigator before Linné has ever described such interesting examples of terraced shore gravel as the deposits at Kapellshamn and Hoburgen; and even now it would be rare to find anyone who could count 77 similar successive ridges. From the manner of his statement the impression may almost be conveyed that Linné doubted whether each ridge really represented the lapse of a year; at least he intimates that such a supposition would lead to rather peculiar deductions.

The ridges we have just mentioned have been investigated by Doctor Munthe, the government geologist, who has kindly acquainted us with the fact that the upper ridges date from the period of the Ancylus Sea, but the others from the Littorina period.

Certain rock formations, on Gotland popularly known as "raukar", gave Linné further confirmation of the higher water level of ancient times. He left a most detailed description of a collection of the latter at Kyllei, together with a drawing of them.

* * * Between Stranridaregarden and the limekiln at Kyllei a sloping hill ran along the bay shore on which several large and thick blocks of limestone from 24 to 36 feet high were standing in rows like the ruined pillars and arches of some church or castle. Those at the foot of the hill were higher than the upper ones, so that all the blocks seemed to reach the same height. From a short distance they resembled statues, busts, horses, and I know not what kind of ghosts. It is certain, however, that all these were formerly part of a limestone rock, and that at the time the retreating sea reached their level they were polished, scoured, cut asunder, and actually sculptured by the surging and booming breakers into the shapes they now present. We can not doubt

the ability of the water, which had scoured the sides of these stones to such an extent and narrowed their bases, to carry away or erode the intermediate bottom. We found similar "stone giants" near Slite of the same size and height.

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This explanation of Linné as to the origin of these "raukar" is, as is well known, quite correct, and is fully recognized as such at the present time. * * *

To quote further from his lecture on the growth of the habitable land:

The two large mountains on Gotland, "Torsburg" and "Hoburg," have perpendicular sides of limestone striated and hollowed out by wave action when the sea covered all Gotland with the exception of these two rocks which rose above the surface in the way that the "Charles Islands" do at the present time.

This observation is quite correct, as Gotland was at one time entirely covered by the post-glacial sea, from which it later rose.

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Besides shore formations and the action of the sea on rocks Linné also mentions the existence of large stone blocks, the size of which caused him great wonder, but which he believed to have been transported by the waves from foreign shores:

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The "self-eroding stone," a block of stone lying 1 mile and a half north of Hoburg, was so large that no human power could have carried it thither, and besides it was situated in the middle of the island or about midway between the eastern and the western shore. This variety of stone was quite unusual in that region, a circumstance which caused the peasants to urge us to inspect it, believing that it contained some metal. The block was 3 yards high, 7 yards broad, and scarcely 6 feet between the east and west sides; it was lying entirely above the surface and consisted of red spar, resembling an Åland-stone, between the grains of which appeared a black glimmer which shone like gold in the sun. By constant exposure to the sun the southern side of this block had been made so brittle that it seemed to consume itself, and the gravel which had fallen from it formed quite a barrow all around, particularly on the south side; hence this stone was "self-eroding," and contained no ore. Since all *saxa*, or granite, is formed underground, and since this block was entirely above ground in a place where there was no higher land and where all else was limestone, it is difficult to understand either its present position or whether the sea had been powerful enough to roll it from Sweden or Russia at a time when this place was under water.

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This block probably still exists and should by all means be exempted from destruction, both because of its being unique as a natural monument and because of Linné's remarks concerning it. * * *

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Thus Linné became the first to announce the existence of a block of one of the "rapakivi" species on Gotland, rocks which have played such an important rôle in the study of the glacial drift.

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During the journey to Westrogothia (1746), Linné had still further occasion to observe evidences of a former higher sea level, and his comparison of the coast and the outlying archipelago is interesting as an illustration of different stages in the emergence of the land from the sea. * * *

It should also be remembered that Linné quite correctly attributes to the former action of the sea the origin of the peculiar forms of erosion and grotto formations found in certain parts of the lower red limestone cliff at Kinnekulle.

Brattefors, at the end of the large meadow opposite Klefwa Church, was well worth inspecting, both on account of its perpendicular height and its peculiar shape; it was thirty-odd yards high and consisted, so to speak, of closely spaced, rounded pillars; these columns exhibited horizontal striæ showing the action of time and waves at a time when the land below was covered with an annually retreating body of water. The mountain consists of reddish limestone and rests on a firm slate foundation. At the foot there is a grotto in which several persons may sit perfectly dry under the water as it rushes down from considerable height.

According to the government geologist, Dr. A. G. Blanthe (Kinnekulle's various soils. S. G. U., ser. C., No. 172, Stockholm, 1901), the marine border of the Yoldia sea corresponds largely with the lower limestone bed of Kinnekulle, and Linné's hypothesis that a shore formerly existed at this place, at which time the limestone was excavated in the manner described, is consequently correct. In the Œconomia Naturæ "Brattfors in Wæstergœtland" is cited as one of the places where the sea formerly raged.[a]

* * * * * * *

The shell banks in Bohuslän have long been well known and were cited by Swedenborg in 1719 as evidence of a former higher water level. They were also investigated by Linné, who described the most common of the shell species found:

The "shell mountains" are justly considered one of the greatest natural wonders of Bohuslän, as they are situated on dry land, sometimes nearly 1½ miles from the sea. These mountains consist of the shells of mollusks. * * *

Under the black surface soil, which was rarely more than 3 to 6 inches deep, occurred the shell stratum, some 12 to 18 feet in depth, underlaid by pure clay. No shells were seen in the bare and hilly mountains above this stratum. * * *

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* * * All these shells belonged to marine forms similar to those which exist partly on our own shores and partly on the coasts of Norway, England, and France. It may thus be reasonable to believe that when the sea surrounded the "shell mountains," the greater part of the archipelago outside being submerged, there was here formed an embayment into which these shells were driven by strong west winds. It is not strange that some of them have sought a more southern refuge, since similar conditions may be observed in the Holland herring. These existed first in the belt, and later on our coasts, and now have reached "Lovers Banc."

[a] This paragraph appears on page 46 of Nathorst's paper.

Hence Linné came to the conclusion that the sea, at least partially, had "changed its inhabitants." The belief in a southward migration was quite natural at a time when the mollusk fauna of the northern seas was unknown.

The account of Linné's travels in Skåne, with a single important exception, contains almost no contributions to the knowledge of a former high water level during the Quaternary period—a natural consequence of the fact that a large part of the territory in question was situated above the post-glacial marine border, which, in southern Skåne, extends only 3 or 4 meters above the sea. The exception referred to is Linné's description of the old beach, or "Jära Wall," as it has been known in geological literature since the days of Sven Nilsson. Linné had recognized an old beach in the sandbank or raised beach on the eastern coast of Öland, and he therefore calls the "Jära Wall" by the same name.

The "Landtborg," or a shore which was somewhat higher than the surface of the land, extended for 3 miles along the coast from Trelleborg to Fredshöga. It was broader on the seaward side, and its highest point was about 60 to 100 paces from the sea; it was 2 yards higher than the land proper, and at this place rose some 6 yards above the sea level.

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Besides the above, Linné's measurement of the distance between Stafsten and the seacoast shows his unflagging interest in everything connected with the question of the decrease of water and the growth of land: * * *

The "Stafsten Rock" was situated 1½ miles west from Trelleborg and toward the coast. This place is renowned because of the fact that the late King Charles XII landed here on December 13, 1715, afer his absence in Turkey. Stafsten rock was somewhat higher than an ordinary man, narrow and almost square. Here we noted the water level in order that posterity may ascertain whether the water rises or falls. On the nearest seashore to the south of Stafsten rock there are two cliffs to the east and west, of almost equal size, which now were nearly 6 inches above water. Beside this there was, on the very shore, and somewhat easterly from a direct line between Stafsten rock and the coast, a block of whitish granite about 9 feet long and almost 6 feet broad. This rock or slab has two corners pointing southwest, of which the more westerly one at this time accurately located the line separating the sea-water level from the dry land. The distance from Stafsten to the water's edge was 357¾ yards.

It was fortunate that Linné left so detailed a description since it has thus been possible to ascertain the fact that the statement of the distance contains a typographical error, the true distance being 157¾, instead of 357¾ yards. * * *

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A review of Linné's contributions to the question of the decrease of water or the expansion of land shows them to be very compre-

hensive: The indication of conchiferous earth in Helsingland; of shore terraces in Öland, on the island "Jungfrun," in Gotland, and in Skåne; of "rauks" and grotto formations in Gotland and Westrogothia; and finally his examination of the "shell banks" at Uddevalla. He was, moreover, the first naturalist to describe shore lines in the mountainous regions (due to ice-dammed lakes), and not least significant were his repeated utterances against the supposition that the former higher elevation of the water had any connection with the biblical deluge:

He who ascribes all this to the deluge, which came suddenly and passed as rapidly away, is indeed a stranger to natural science and, blind himself, sees only with the eyes of others, provided, generally speaking, he sees anything at all.

Formation of Granite Mountains—* * *—Taberg—The Dala Sandstone — Petroleum — Fossils in Dalarne — Potholes ("Giant Pots")—* * *—The Recognition of Marl and Its Economic Importance—"Marl Stones"—* * *—"Earth Shots"—* * *—Quicksand—The Sea Bottom on Shallow Coasts.

The geologic character of the region surrounding Linné's home, which must have made a deep impression upon him when a young man, is monotonous in the extreme. Bed rock exposures are exceptional, and, where there are no peat bogs, the soil consists almost exclusively of gravel (partly moraine gravel and partly rubble), inclosing more or less larger stones which are also scattered about on the surface. One may travel for many miles in this region without seeing a single outcrop.

These conditions seem to offer an explanation of Linné's peculiar view that "granite, of which most of our mountains consist, is found to have its origin in chessom, and that it is most frequently formed when the soil is mixed with particles of iron." This chessom, or *argilla grandæva*, is characterized in the Systema Naturæ as a siliceous or sandy clay, which is rather soft in the spring and fall, but so hard in summer that it can not be broken readily without hammer or chisel; it is said to exist in Dalarne.

* * * * * * *

* * * In his speech on the growth of the habitable land he says that if large blocks of rock were broken they would be found to consist of mica, quartz, and spar.

This affords clear proof that they, like all other stones, originated through coalescence of the soil, and that they were therefore formed underground.

From large pieces of rock to isolated cliffs consisting of the same minerals, the step was a short one, and we may thus understand how Linné derived his peculiar view of the origin of granite. It may

seem strange that he did not abandon this opinion when he became acquainted with real granite mountains, but he supposed these to have been formed underground. That the blocks are now seen "carelessly thrown about" over the surface of the earth was, according to his belief, caused by the action of water in freeing them from the surrounding soil. Thus the cliffs—

which had their origin in the ground could now project so high above the surface because the waves of the sea had removed the surrounding soil and gravel.

In his notes upon the neighborhood of Upsala, he adds:

The second cause is the rain which yearly washes off the heights and fills up the valleys, a process in itself rather unobstrusive and gradual, although accomplishing much in the course of ages. * * *

Strange as Linné's opinion of the formation of granite may seem to our minds, it is easily explained if the geological character of his home surroundings is taken into consideration, together with the fact that petrography as a science did not exist at that period. He says, in the account of his journey in Westrogothia:

Lithogeny is quite a simple matter, although somewhat obscure, owing to the few researches that have been made in our times. * * *

* * * * * * *

During his travels in Dalarne (1734) Linné had an opportunity of observing the pre-Cambrian Dala sandstone, which he had so carefully examined in the millstone quarries at Malung and on which he had noticed peculiar sun cracks. The first block showing such a design was observed in the aisle of the church at Elfdal, and is described as—

engraved *reticulatim* with several characters, but the writer has so completely ignored any sequence or continuity in the drawings that they seem just as strange as the language and style.

Another block was seen in the cemetery at Särna:

It was to be seen at once that the style of writing was the same as that in the church at Elfdal, except that this one was so much more ornamental.

Although Linné could not explain the origin of these drawings, he insisted that there could be no question of a *lusus naturæ*. Of special interest are his remarks on the wave marks commonly found in this sandstone. On August 1, while between Särna and Lima, he says:

Here the species of stone which we had formerly observed was found in abundance, and consisted of a red, hard, firm sandstone; on one of its uniformly flat surfaces are seen longitudinal and parallel cavities which resemble the marks produced by drawing one's fingers over hard snow; but their origin, taking into consideration all previously observed stones, could not be determined.

On the 4th, however, the true explanation was given:

Everywhere in this neighborhood there was plenty of this red, "engraved" sandstone, with apparent wave marks which were much clearer than on any

previous specimens. Some believe the marks to have been caused by water, because they greatly resemble a sandy sea or river bottom which had been sculptured by the waves of the deep. * * *

During his journey in Dalarne petroleum was also for the first time discovered in Sweden, partly in the limestone quarries at Skärbacka (in Osmunds Mountain), at Kärfsasen in the parish of Rättvik, and partly in the lime at Grana. Linné emphasized this fact in his speech on the necessity of journeys of exploration within the country thus:

Perhaps you, my auditors, refuse to believe me when I say that in Dalarne there are entire mountains saturated with petroleum, but let your doubts be gone! With my own eyes I have seen this, a fact never before seen or heard of. * * *

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The presence of petroleum in these localities gave occasion much later, during the years 1867–1869, to several mining enterprises, which, however, as is well known, resulted in complete failure.

Linné's observations on the Cambro-Silurian strata in southern Sweden will be quoted in the succeeding chapter. Those concerning Dalarne may, however, be cited here, as they are few in number and have little in common with those of Sweden.

The mines at Bodback contain white or red lime, of which the red is so full of white fossils that there does not seem to be space enough for another one. Bauman's celebrated "Höhle," with its many foreign fossils, is as nothing compared to this. Yet they are so little thought of that they are broken up and used, instead of turf, in thatching roofs.

He then describes the most common fossil (*Nautili articulati*), which clearly belongs to the genus *Orthoceras*.

Of what they are petrifications nobody knows * * *. They are not cochleæ, nor burbots, as some suppose. There are more fossils in the stones than grains in porridge. * * *

From the journey in Dalarne there is also an account of a large pothole at Dala River, which is described, quite correctly, as having been formed by the "continuous rotation of the stream." In the journey in Westrogothia mention is also made of the existence of a couple of potholes in the neighborhood of Gothenburg.

A couple of "giant pots" were seen not far from the strata and at a distance barely equal to two gunshots from each other. They were cylindrical holes bored deep in the mountain, and were 1 yard deep and 1 yard broad. One of these pots was on the side of the mountain, on a gentle slope, but the hole was vertical, regardless of the slope.

During the journey in Skåne another pothole is also mentioned:

A Jetta well, as a "giant pot" is called in Westrogothia, was seen on Jettebrunsliden, a hillside which one traverses on the way to Stockatorp. Here was a pothole on the top of the cliff facing the sea, more than a yard in depth and

breadth, and neatly hollowed out. If all "giant pots" are formed by the water, as we believe at the present time, then this pot, situated so high above the water, must doubtless be several thousand years old.

At a time when the existence of the glacial period was unknown no other explanation than that given by Linné could be advanced, and especially remarkable is his emphasis upon the peculiar characteristic of these potholes, i. e., their vertical position even on a mountain slope. Nor should we forget what he says about the great age of the one last mentioned.

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* * * During the first day of his journey to Skåne (April 29, 1749), he records an occurrence of marl which must have been of great importance at that time:

Marl ("earth marrow") existed in larger quantities in the neighborhood of Upsala than in any other place, a fact which to a great extent contributed to the fertility of these fields. * * * By the use of marl or "earth marrow," as some call it, the English and French have brought their cultivated fields up to a high standard of productivity, for which reason our nation, during the last years, and especially since we began to pay more careful attention to agriculture, has been anxious to ascertain whether such a useful soil could not be found at home. We therefore secured samples of marl from England, France, and the Netherlands, but because of variations in color and composition it was difficult to find a method of distinguishing the marl, until it was noticed a year ago that all marl seemed to ferment in contact with sour liquids, such as vinegar, diluted nitric acid, and other such fluids. Hence the conclusion was arrived at that marl was nothing else than a lime clay or chalk clay, and only a bleaching or leavening soil which has retained its ability to break up the alkalinity of the ground, which is unhealthy to plants * * *. From the foregoing a farmer may now readily detect true marl, because a clay which is mixed with marl will effervesce if a few drops of aqua fortis be poured over it. If the same clay effervesces in the presence of vinegar, however, the marl is still better, because many a clay that contains but little marl and which will ferment when mixed with aqua fortis will not ferment when mixed with vinegar alone.

* * * In another place in the description of the same journey Linné states that it was "the vice-president, Baron S. C. Bjelke," who in 1748 first discovered this manner of detecting lime-bearing clay or marl.

Linné applied this experience during his travels in Skåne. He dwells upon the barrenness of the country around Åsum, Köping, and Maltesholm, south and southwest of Christianstad. * * * Subsequently he emphasized the good results which might be obtained by mixing the sandy soil with marl, and proposed that about half an acre be marled by way of experiment.

If this theory be confirmed by experience, opportunity will thus be afforded to transform this entire sterile plain into the most magnificent soil, with incredible advantage to the farmer and the country.

These words were prophetic, because it is well known that the use of marl has substantially benefited the development of agriculture in Skåne. This occurred much later, however, and it appears that Linné's exhortation was at first left unheeded.

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Wind-blown sand seems to have been an object of special interest to Linné, and his descriptions of fields of this sand and their drifts are very picturesque. In the Öland journey he gives an account of such fields from the northern extremity of the island:

From the "Sjötorp" we started out for the next village, Grankulla. As soon as we had passed by the latter the whole region between the village and the sea was seen to be full of sand hills.

The sand was driven from the sea and scattered over the entire field by a strong south wind. The sand did not fall until it came to the calm precincts of the forest, where the violence of the wind died out. Great sand dunes were here to be seen, like giant snowdrifts, on the sides of the forest, burying large pine trees so that often barely one-third of the top of the trees could be seen sticking out of the drifts. The trees were thus gradually smothered, because the sand prevented the penetration of any life-sustaining rain water or dampness, and as the outer trees successively decayed the sand drifts moved annually farther and farther into the forest. It seemed rather curious to run about on these sand difts and botanize between the tree tops. The sand in no wise resembled the heath sand of Skåne, but was of a much coarser marine variety. It was quite white, consisting of clear quartz and a little red spar, but so rough and uneven as to be unfit even for scouring purposes. On the side toward the field the drifts were practically flat and showed waves and undulations like those of a sea bottom, but on the inner side, toward the woods, they were so steep as to be scarcely accessible by climbing, and about 24 feet high.

Linné further mentions the occurrence of "sand oats" or "shore rye" among the sand at this place:

This "sand oats" is the same as the Dutch use to sow on their dunes in order that the sand may become firm ground. It has also been recommended for the fields of Skåne.

* * * * * * *

Linné studied the drift sand in many places in Skåne, mostly at Ahus and Angelholm:

There was plenty of wind-blown sand in the high-lying fields on both banks of the river at Ahus, but mostly on the southern. The sand is quite white, clear, and fine; the reason being that if any coarser pieces or gravel are mixed with it they remain where they are when the finer sand is blown away. The wind often carries the sand a distance of 1½ miles, a fact which is best seen on the snow in winter time. Thus the sand makes the rivers shallow and intermingles with the ground and fields. * * * Wherever a juniper or crowberry bush or a willow was found on these hills it was quite covered over with sand, forming a big knoll, above which only the ends of the branches could be seen. In many places where shrubs and grasses had grown large hillocks or small hills had been produced through the sand gathering and mixing with the straw, and again where this grass had disappeared it was

noticed that the wind had made a hole in the side of the hill and had carried away some hundreds of wagon loads of earth. Likewise in other places hills had been cut into by the wind, exposing several strata of black mold two fingers thick, a sure sign that the hills had changed their former nature. Thus never resting Nature plays her pranks and builds up and changes everything continuously.

In speaking of the wind-blown sand at Angelholm * * * Linné again and more explicitly compares it with snow:

The blown sand when it is thrown up in drifts reminds one to a certain extent of snow. It is almost as white; it is massed by the wind into drifts of considerable height, where there is a resistance to the wind in the shape of fences, villages, or the like. When it is piled up on both sides of a pole fence the largest quantity, which is flattened out, is found on the leeward side and has a sharp edge at the top turned to windward; it sweeps the ground, and where there are hillocks it is massed in a long slope behind, not in front. Like snow, its upper part becomes harder, takes on a crust, and shows small creeping lines on the surface, just like snow. * * *

This chapter would not be complete if I did not quote Linné's observations on the nature of the sea bottom at shallow and sandy shores. On the trip between Altona and Amsterdam (1735) he had an opportunity of examining such a bottom, of which he (in the Iter ad exteros) tells the following:

May 24.—We landed on an island in eastern Friesland named Nordenoge. * * * One could here easily observe the appearance of the sea bottom. It consisted of a fine white sand which, when dug into, became of a dark gray color, apparently indicating iron. On the top of each elevation there were some small transverse *lineæ undulosæ* from the water [wave marks]. Everywhere there were small *monticuli*, of the size of half a handful of earth, with rings of sand resembling pastry or like a big bunch of crawling worms. Underneath these there were large *lumbrici* like earthworms, *sed punctati, elevati*, which resembled sausages filled with sand instead of meat. *Forte diversa species* [sand worms] were evenly distributed over the whole bottom in incredible quantities, evidently serving as food for the fishes, and so equally spaced that they seemed to have been quartered there. Between these *monticuli* there were scattered about, although *pauciores, excavationes semiovatæ*, with a hole in the middle. What these contained I do not know; neither do I know whether or not *lumbrici* had caused them. When I dug into the bottom there were also found *Juli rubri, longi.*

During the journey in Westrogothia Linné made similar observations on the coast of the island of Orust. * * *

We here waded out into the sea until the water was more than knee-deep, botanizing on the sea bottom; we found *Zosteram, Ruppiam*, borings in the bottom, small elevated worm heaps, and other diminutive things. * * * We noticed that in several places the bottom was bored through with pairs of holes not as large in circumference as two fingers, which were always grouped together by twos, never singly or by threes. * * * The handle of a tobacco pipe went down vertically about 9 inches and then struck against something hard, like a rock; * * * but whenever we commenced to dig with our hands we found at the bottom of each pair of holes a large mussel. * * * Consequently the mussels must have made these holes; but to ascertain how they

had been made by the mussel or how it had got so deep down into the sea bottom was a more difficult matter. * * * Numerous as this mussel was beneath the sandy bottom we saw no traces of it on the shores, nor have I ever seen one of them in Sweden. * * * Nearly all mussels living in the sand and slime of the sea bottom have two tubes protruding above the bottom through which they breathe the water.

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* * * To quote these observations in an article intended to describe Linné as a geologist may seem somewhat curious to many; but the fact is that here they are in their proper place, because it is through the observation of phenomena along modern shores that the geologist is enabled to interpret the true meaning of various characteristics of older deposits. * * *

ROCK STRATA AND FOSSILS OF ÖLAND AND GOTLAND—HAVE THE ANIMALS MIGRATED OR ARE THEY EXTINCT?—THE MOUNTAINS OF WESTROGOTHIA—STRATA TERR. THE CAMBRO-SILURIAN STRATA OF SKÅNE—LINNÉ, BERGMAN, AND WERNER.

That Linné, during his travels in Öland and Gotland, should have made a number of observations of local rock species was only what might have been anticipated. * * * But he was also in the habit of making excursions to Malmö and Lomma, upon which occasions "petrifications were collected in the sand on the seashore" (presumably mostly cretaceous fossils and siliceous stone nuclei). Moreover, during his travels abroad he had had abundant opportunities of studying fossils in the natural history collections, and * * * it becomes quite clear that Linné, through his own experiences as well as from the works of others, was quite familiar with fossils as such. Moreover, during his journey in Dalarne he had also had occasion to study their occurrence in the rock strata.

He describes the slate under the limestone at Erischsö, in Öland, gives an account of the succession of strata in the alum pit, and mentions from the limestone at Böda—

several petrifications, such as "Öland snails," here called "Darts" [*Orthoceras*], *Entrochi* with many rings [stalked crinoids], round and rough-surfaced pyrite balls, and "Crystal apples" [cystids]:

"Crystal apples" I call the spherical stones, of the size of apples, that are found in limestones, which, when broken, resemble a *hæmatites*, and consist entirely of light and transparent spar crystals which converge in centro, leaving a cavity in the center, so that their triangular points may be plainly seen. These "crystal apples" are rather common here in Öland and I have collected them at Osmunds Mountain in Dalarne. * * *

At different points in the lime quarries at the northern end of Öland Linné had occasion to observe the profuse occurrence of Orthoceratites:

"Darts," or *Helmintholithus nautili recti*, were abundant in this rock, but particularly in the red one with blue streaks. * * * We searched in vain

all over the shores of the island for the shell, of which the "darts" that here occur in all the rocks are undoubtedly fossils. Such "darts" are here often found entirely hollow, so that *crusta* and *dissepimenta* are lying around quite empty.

In another place he says:

* * * When the flakes were separated from each other these "darts" or "Öland spikes" could be seen packed as tight together as husks in coarse bread, so that God alone knows where so many rare shells come from.

A fossil, quite rare in other places but common here, resembled a *valvula Echini*, often as large as the palm of the hand, but otherwise crescentlike in shape, with two parallel grooves and several transverse stripes.

The last-mentioned fossil, of which Linné's original figure is here reproduced, is apparently the pygidium of a *Megalaspis*, which is quite common in this limestone. The most interesting circumstance connected with the above-mentioned quotation is of course Linné's consternation at the fact that no *Orthoceras* shells were found cast up on the shore. * * *

Two years later (1747), however, during the journey in Westrogothia, he mentions the occurrence of Orthoceratites in the limestone at Kinnekulle in the following words:

"Pizzles," or "stone butts," are the popular local names for the same kind of stone which occurs so abundantly on Öland, and there was called "Darts"; and, exactly as in Öland, there was a profusion of them in the limestone. They are nothing else than the fossil of a species of mollusk called "*Nautilus rectus*," the petrified shells of which are of the most rare in all shell collections. * * *

In the Museum Tessinianum he says:

* * * That these creatures formerly existed in enormous multitudes in Sweden the lime cliffs on the shores of Öland, where they lie as thick as chaff in wheat, convince us; but now the animals have so completely disappeared that I have never seen one of the shells in a collection of mullusks, and therefore they are generally classed among the extinct species of Europe.

In the Systema Naturæ (1768), he says:

Habitat sine dubio in abysso maris Baltici; deperditus; * * *

Linné seems to mean by this expression that Orthoceras shells may still be found in the deepest recesses of the Baltic, while the animals themselves were extinct.

On Gotland Linné had a similar experience with corals. At Visby he immediately noticed their occurrence—*Madrepora simplices* and *Madrepora aggregatæ*—"a couple of fathoms above the sea, in great numbers," and in the limestone at Hangvar he alleges that there were "very many *petrificata*, especially *Entrochi*, and a species of coral which resembled *Lycopodium* or Club moss." The richest collection of corals was, however, made at Kapellshamn:

* * * The Madreporæ at the water's edge were pure and clear and studded with stars like the reverse side of a playing card or the pores of a

honeycomb. Each star or tube was in the shape of a hollow cylinder with 19 to 20 hollow squares forming the periphery. These tubes when sawed off crossways had all their cavities filled with lime and were polished, showing an exact likeness to the reverse side of a card. But if these stones were broken lengthwise they looked like a folded net with its *lamellis perpendicularibus* and *transversalibus decussantibus*. Also other *Madreporæ simplices* were seen here that resembled calf's horns, of about the length of a finger and having at their thickest end only one star. Others resembled small cups or goblets; others again were many times *prolifcræ a centro*, like Polytrichum or golden maiden hair, where one cup was inserted in the other. All these coral stones are, according to the discovery of the learned botanist, M. Bernhard Jussieu, nothing else than shells elaborated by small worms that make these stars and stone crusts, there being worms or *Medusæ*, *Hydræ*, and *Polypi* of as many different kinds as there are species of Madreporis. The animals which build our corals are yet undescribed, but I must leave them to be examined by others who have more time, and who can select both suitable time and weather to fish for them in the bay at Kapellshamn. * * *

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From "Stora Karlsön" Linné writes as follows:

Madreporæ, or star corals, were plentiful on all the beaches. * * * I omit enumerating the corals, especially as all Gotland corals which I found during this trip are at present the subject of a disputation, under my Præsidio, recently published in Upsala, by the auscultator auxiliary, Henr. Fougt. * * *

* * * We now know that this treatise was written by Linné, but foreign scientists who had no knowledge of the custom prevailing with us at Linné's time—that is, that a university professor caused his disquisitions to be published by a pupil and argued through the latter at a formal act of disputation where he himself presided—have quoted Fought as the author of a paper. G. Lindström, in an essay entitled "On the Corallia Baltica of Linnæus,"[a] has explained the truth of the matter, and even quoted the proofs of the fact that Linné was the real author of the paper, as is incontestably shown by a letter from the latter to one A. Bäck. In the same work Lindström accounts for the species described in Linné's article, and from this account it is clear that the described and reproduced corals belonged to no less than 23 species, of which 18 have been identified without a doubt and 4 only tentatively, because one of the figures is of an indefinable nature.

In the collection there are, further, four bryozoans, of which one, however, is not fossil, but recent. It was thus a paleontological work of some magnitude for its time that Linné here achieved. * * *

As we have seen, Linné at first believed that the corals were still to be found living in the Baltic, but in the Museum Tessinianum,

[a] "In Ofwersikt af Kungl. Vetenskapsakademiens Förhandlingar. 1895." An account is also given here of the fate of the collection of fossils after it had come into the hands of Sir James E. Smith and subsequently into the possession of the Linnean Society.

which was published in 1753 and, consequently eight years subsequent to the description of the Öland journey, he expresses his doubts as follows:

> The native [corals] that are thrown up annually on the seashore at our Belt [the Baltic Sea], particularly at Gotland, I have never seen fresh, so that I may well doubt whether they are actually still with us or whether they, like the brachiopoda, have long ago migrated to an unknown part of the world.

In the Systema Naturæ (1768), 3 Tubiporæ and 7 Madreporæ among the fossils are quoted as "*deperditæ*," and concerning these the following statement is made: "Habitant in Mari Baltico, cum quotannis ad Gotlandiam rejiciuntur, deperditi," an expression almost identical with that used for the Orthoceratites. A part of the Gotland corals are, however, not included among the fossils, but among living animals, an uncertainty which has already been pointed out by Lindström. This doubt becomes natural, however, in view of what Linné says in the Museum Tessinianum about "*Porpita, Helmintholithus zoophyti medusæ*, 'sea penny,' vomit of jelly fish." which he states are of common occurrence in Gotland and Öland:

> The mother of this stone is like a small jelly fish and of exactly the same shape. The animal was taken some years ago in the Sargasso Sea of the East Indies and donated to the natural history collection at Upsala by M. Lagerström, councilor of commerce, so that both the animal and stone could be seen there. Until quite recently it was believed that this stone was the germ of our Gotland corals, called "rams' horns," or at least that they were a coalescence of clay which had got into the star of the coral and there become solidified, and nobody could ever have believed that it would be necessary to look as far as the Indies for their origin.

I do not know to which animal Linné here refers, nor is it essential to the question at issue. What is most important, however, is the fact that he believed he had found one of the Gotland corals (*Madrepora simplex orbicularis plana, stella convexa=Palæocyclus porpita*) in an animal brought home from the East Indian seas. It is thus quite natural that he should have thought that the same possibility might apply to some of the others. His uncertainty in this matter, which we have mentioned, may therefore rather be considered as a praiseworthy caution in the face of the doubt as to which animals still remained to be discovered in distant seas.

In this connection might also be quoted what Linné says in the Museum Tessinianum regarding the ammonites and brachiopoda. About the former he says:

> The origin of all these is unknown because the shell of the animal has neither been found in Europe nor seen in any of the collections, and therefore it is generally accounted among those entirely extinct. There is no trace of these creatures except where they had been impressed in the rock, and the only way to ascertain the species of these *Nautili* is from the rocks.

After having described several "wild mussels" (Anomiæ), Linné remarks:

The animals which inhabited all these "wild mussels," as well as the unaltered shells, are nowadays unknown to us, as we never find them in any of the collections of mollusks, nor do we know what in the world may have become of them. Still, we shall never believe that a species has entirely perished from the earth.

That Linné believed that the seas were all too insufficiently explored for anyone to form a decisive opinion as to whether the animals in question really were extinct is shown with desirable clearness from what he says in the same work about the belemnites:

No matter how common these may be now, their origin, as well as that of the ammonites, "Darts," "Brattenberg's pennies," and Brachiopoda, remains entirely unknown. Perhaps all these animals sustain themselves in the deepest parts of the sea, and never come ashore. It would therefore be desirable if those who go to the Indies would search the Sargasso Sea and find out whether they do live there now.

At the present time even the layman knows that rock strata contain numbers of extinct animals, but this fact had not been established at the period in question. It may, for example, be remembered how Scheuchzer interpreted the giant fossil salamander from the stone quarries at Oeningen to be the skeleton of a man who had perished in the supposed "deluge." Linné's opinion that distant seas should first be explored before drawing any conclusions as to whether the animals in question were extinct or not was evidently the right one. That the conclusions arrived at were sometimes rather hasty (as when groups of animals which have living representatives at the bottom of the sea were supposed to be extinct) is shown among other things by the discovery of *Rhizocrinus lofotensis*, a discovery which caused such excitement at the time it was made.

At Bursviken on Gotland Linné had an opportunity of observing cobbles of the kind of limestone known as "oolite," or "fish roe stone," and on this occasion he expressed himself against the opinion that it might be petrified fish roe.

The cobbles of the uppermost "auren" are of a species of stone called "Oolithum" by the *Lithologi*, because it consists of a white hailstonelike rock having one crust outside of the other, just like a crab's eye [eyestone], or sugar pill. Those who have proclaimed that such an *Oolithus* was nothing else than petrified fish roe would here have an opportunity of seeing more stone roe than ever there was true fish roe in the world.[a]

* * * * * * *

[a] In the Systema Naturæ the oolite is mentioned among the limestones (not among the fossils), and of its origin it is said: "Natum e calce coalescente fluctibus maris rotundata," i. e., it is considered as a purely mechanical formation.

[a] The succession of strata in several of the mountains of Westrogothia was already known in a general way before Linné's visit there (1746). Swedenborg [b] had accounted for the strata of Billingen * * * and Linné's pupil Kalm [c] had paid a visit to the mountains of Kinnekulle, Halleberg, and Hunneberg, leaving a description containing an almost complete account of them. * * *

The first of the Westrogothia mountains visited by Linné was Kinnekulle, of which he states in his travel description:

> Kinnekulle is one of the most remarkable places in the country, because of its peculiar situation and shape. This Kinnekulle is a mountain with broad and extensive terracelike deposits * * * [of different rock species] which extend almost horizontally around the center of the mountain. These terraces are also separated by abrupt perpendicular precipices or cliffs resembling the very highest church or castle wall. * * *
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> * * * * * * *

In the description Linné distinguishes, from below upward, the following strata, the height and length of which are indicated on a sketch accompanying his paper:

(*a*) The Sandstone Cliff.

(*b*) The Limestone Wall, consisting of several kinds of limestone (limestone proper, liver stone [hepatic pyrites], "stinkstone"), and Crow Mountain; this layer is covered with red soil, in which black flints are often found.

(*c*) The Redstone Cliff, consisting of "Ölandstone," of three different kinds; that is, undermost, "green slate-pencil stone" (Griffelsten), and above this, first gray and then red "potstone."

(*d*) The Gorstone Cliff, "a coarse knotted limestone that can neither be used in limekilns nor for stone polishing purposes, and called by the peasants 'Gorsten'".

(*e*) High Hills, consisting only of round graystones.

(*f*) Crow Mountain, "of black slate, strong and thick."

(*g*) The Highest Hill, "of coarse and hard sandstone." [d]

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[a] The paragraph immediately preceding this paragraph occurs on page 719.

[b] Relating to this, see Nathorst, A. G.: Emanuel Swedenborg som geolog. Geol. Fören. i Stockh. Forh., vol. 28 (1906).

[c] Pehr Kalm's Wästgotha och Bohusländska resa förröttad år 1742. Stockholm, 1746.

[d] The layers cited by Linné correspond to the following strata (compare G. Holm: Kinnekulle. S. G. U., ser. C, No. 172, Stockholm, 1901), according to the nomenclature now prevailing:

(*a*) The Sandstone Cliff=the sandstone layer.

(*b*) The Limestone Wall=the layer of alum slate. Linné was the first (Holm, loc. cit.) to notice the occurrence of flint.

(*c*) The Redstone Cliff. The green "slate-pencil stone," or "griffelsten," which according to Linné is the undermost layer of this cliff is, according to Holm, the lower graptolite shales. Linné's "Potstone" is the Orthoceras lime-

This last-mentioned statement that the "highest hill" consisted of sandstone, * * * is palpably a slip of the pen and should be graystone, because only a few pages farther on in the latter it is said:

> The uppermost hill consisted entirely of graystone covered with soil. * * *
> * * * * * * *

The most remarkable part of the description, in which he goes into a detailed account of his opinion in the matter, reads as follows:

> The strata terræ everywhere around Mösseberg, Ålleberg, and Billingen are all like those of Kinnekulle, so that when one exactly knows the rock layers of Kinnekulle, one also knows what may be found all over in the depths. * * * These strata extend even farther; * * * thus the profile of Kinnekulle may serve as a clew to the strata terræ or anatomy of the earth's crust, not only here in Westrogothia, but perhaps of the greater part of the world.
>
> Lithogenesy is a simple enough matter, although still quite obscure owing to the few researches as yet made. We know that the sand of the sea becomes sandstone, the compounds of the sediment of the sea clay, the clay becomes lime, the lime "blecke" [chloride of lime], the "blecke" chalk, and the chalk silex or flint. Peatbog mud becomes slate and the slate again surface soil. We see that spar, quartz, and rock flint, together with mica, are formed where the rocks have cracked and join them together. We see that graystone is formed from loose friable material. * * *

* * * The statements made in the last paragraph but one * * * open up at once a conception of a uniform succession of strata all over the globe, and in so doing lay the foundation for stratigraphic geology and the knowledge of the history of the earth in complete accord with the words often cited by Linné, "that the stones shall speak for themselves."

It should be emphasized right here that Linné nowhere mentions anything about the strata underlying the sandstone layer of the

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stone, but supposedly owing to an error in the writing Linné states that the undermost stratum of this is gray, instead of red. There are, of course, actually four divisions of the Orthoceras limestone, which, according to color and succession (from below upward), are distinguished as the lower red, lower gray, upper red, and upper gray.

(*d*) The Gorstone Cliff=the upper gray Orthoceras limestones. (Holm, loc. cit.)

(*e*) High Hills, where Linné did not notice any bedrock exposure but only loose blocks, must be considered as corresponding to strata which are now called the Chasmops limestone, Trinucleus shales, and Brachiopod shales.

(*f*) The Crow Mountain=the upper graptolite shales.

(*g*) The Highest Hill=the diabase cover (trap).

It is thus only the Ceratopyge limestone, between the alum and the lower graptolite shales, and the three strata just mentioned (the Chasmops limestone, the Trinucleus, and the Brachiopod shales) that Linné did not observe. When it is taken into consideration that he stayed in this place but three days, and that he also made a number of botanical and other observations and notes, it must be admitted that he made good use of his time. * * *

Westrogothia Mountains, and in the Curiositas Naturalis he comes right to the point, "but what then follows (i. e., below the sandstone) I do not know." His opinion of the formation of rock strata at the bottom of the sea is briefly set forth in the 1748 edition of the Systema Naturæ, and the following year (1749) he published an account agreeing with the former, although somewhat more detailed, in the introduction to the Œconomia Naturæ. He assumed that the sargassum or sargasso weed floating on the sea had been of considerable importance in this respect, by quieting the motion of the waves. * * *

In the Sargasso are found species of birds and fishes; that is, those who have floating eggs and species of Vermes, Cochleæ, Conchæ, Corals, Medusæ, etc., other than those known on the shores. These gradually die off and then their bodies sink and mix with the clay, when thus mixed with clay, being themselves covered with limeshells, they change the clay into limestone.[a]

This might serve to explain why such petrifications, Orthoceratites and others, the animals of which are now entirely unknown to us, have been found in the lime rocks of the "*allvar*" of Öland. Kinnekulle seems to indicate similar conditions, and the latter may have originated through the conglomeration of sea sand forming its undermost layer of sandstone, on which rests the slate formed by the black mud or ooze covering the sand of the sea bottom. On top of the last named there is a deep stratum of sandstone full of strange fossils, perchance precipitated through the action of the Sargasso. Upon this last-mentioned layer there is again slate originating from molded Sargasso, and the uppermost part is gray rock formed of gravel, which may be identical with that cast up by the sea when the rock first became a shore line.

It is strange that the uppermost strata of all the mountains consist solely of graystone. From this it may be concluded that they [the strata of graystone] have not been there from the beginning, because the stratum next below is slate, which is always formed from black mold; and as all mold is formed from vegetable growth, there must have been plants before the graystone layer got there, and hence it could not have been created.[b] Those who would attribute all this to the deluge think very little and see still less. A much longer period than the duration of the flood has been required for this.

That the "trap" of the Westrogothia mountains could be accounted for in no other way than did Linné, and Swedenborg before him, is not to be wondered at, as nothing was known at that time either of the enormous streams of lava poured out in violent volcanic eruptions or of horizontal intrusions between the strata.

* * * * * * *

Linné stated his view of a definite succession of strata throughout the world in the twelfth edition of the Systema Naturæ, the third part of which, treating of the mineral kingdom, was issued in 1768. * * *

The fact that Linné's opinions about the Strata telluris were published in the Systema Naturæ caused them to become widely known

[a] See Syst. Nat., sixth ed., p. 219, note 5.

[b] Reisen durch Westgothland, p. 35.

and accessible to the entire scientific world. This fact makes it at once evident that they could not have been without influence on the development of geological science, and, as I have previously pointed out in my work, Jordens Historia, Werner was doubtless influenced by them. This influence seems to have been partly direct and partly conveyed through Torbern Bergman's Physical Description of the Globe, the first edition of which appeared in 1768 and the second in 1773–1774. The opinion of Linné, quoted in that work, as to the formation of the rock strata from marine sedimentary deposits, was revised by himself and is identical with the one we have become acquainted with above. But Bergman built still higher on the foundation laid by Linné, and he recognized the fact that below the stratified rocks there were what he called the "primitive" or "primeval," or what we now term the "Archæan" rock. He further brought the loose earth strata together as a separate group, "flung together" or "piled up" rocks, and in addition treated the volcanoes as a distinct type. The constructive work of geology as a science was thus quite essentially improved and enlarged upon, and through the efforts of the German, A. G. Werner, its framework may be said to have reached its first completion, as the latter divided the stratified rocks into two principal groups, i. e., metamorphic rocks and sedimentary rocks, each with several subdivisions.

Werner has generally been considered the founder of the science of geology, and his merits as such are in no degree diminished by the circumstance that he constructed his system on the foundation laid by Linné and Bergman, a fact which he himself would surely have been the first to admit. If it be asked whether he was aware of the works of the Swedish investigators, the answer would be that he not only knew them, but that he himself had quoted them extensively.

* * * * * * *

* * * S. Haughton, the English geologist, who naturally can not be suspected of partiality in either direction, also says that—

> he [Werner] seemed to have obtained his idea of dividing the rock species according to their order of succession through a study of Linné's work, but he further elaborated this idea in supposing that each different rock species had been deposited during a definite period.[a]

* * * * * * *

It is quite evident that in order to be able justly to determine the value of a discoverer's contribution to science, the position of that particular science during the period of his activity must, as has here

[a] Samuel Haughton, Manual of Geology, second edition, London, 1866, p. 128. In this work "the celebrated Linné" is cited as the first who knew how to assign a certain age to each group of rock species. (This is perhaps somewhat exaggerated). There is further an account of what Linné says in the Systema Naturæ concerning the order of succession and origin of the rock species.

been done, be taken into consideration. If, on the other hand, we look at Linné's arrangement of the strata terræ from the point of view of our present knowledge of them, it certainly appears very defective and incomplete, as it only embraces the Cambrian and Silurian strata, and hence only an inconsiderable part of the entire succession. But the same remark may be made, and has also been made, against Werner's arrangement, i. e., that even the latter was too incomplete. * * * Linné's classification, which was founded on the conditions in Sweden, could apply to no other than Swedish sedimentary deposits. Werner, on his part, founded his classification on the conditions obtaining in Erzgebirge and adjoining parts of Saxony and Bohemia,[a] and hence also within a relatively limited region.

The general conditions at the time of the establishment of Linné's, as well as of Werner's, systems were consequently such that neither could be complete. * * * Each [material structure] requires a firm foundation, and it was Linné who laid the first foundation stone of the science of stratigraphic geology, after whom first Bergman and then Werner continued to build. And through the work of Werner, to complete the parable, the structure reached such a height that it commenced to attract general attention.

Balsberg and other Strata of Skåne Belonging to the Cretaceous Period—* * *—Presentiment as to the Length of Geological Time.

During his journey in Skåne, Linné had an opportunity to study the local Mesozoic strata, partly those belonging to the Cretaceous system and, in northwestern Skåne, partly those belonging to the Lias proper. In accounting for these it may perhaps be most convenient to * * * commence with the rock species now called testaceous lime or shell stone.

* * * Beneath all this was the mountain itself, which was a loose rock of a pale yellowish lime. This limestone lay nearly horizontally, with a horizontal cleavage, and for the most part it was so friable that it could be pulverized between the fingers, although farther down it was somewhat firmer than above. The species of rock is rather rare in Sweden, with the exception of Skåne, but more common in Germany and Spain. Most of the walls in the city of Cadiz are built of this rock species. When this stone is examined closely it is found that it consists entirely of shell gravel, mussels, periwinkles, corals, or of such gravel as is thrown together in sub-

[a] K. A. v. Zittel, "Geschichte der Geologie" und "Paläontologie bis Ende des 19. Jahrhunderts," p. 90. München und Leipzig, 1899.

marine channels and in some places on the shores, so that this entire lime rock is nothing but a cemetery of as many dead animals as there are grains in drift sand. * * * When we now further consider how so many strange animals have come to be buried here, animals that are now scarcely to be seen in Europe, we meet with a new argument which also requires considerable reflection. The Testaceæ or all the genera of mussels that live on the sea bottom, are divided into the Littoralia and Pelagica. Shell collectors call those mussels and shell animals Littorales which do not live in the deep, but only keep close to the shore, so that their shells are cast up on the shores as soon as they die and perish. Hence these shells are common in natural-history collections. On the other hand, Pelagici are those shell animals that exist in the depths of the sea and never come near the shores, a reason why their shells are very difficult to obtain. The depths of the sea are mostly barren and covered with sand or corals, with few fishes and little fauna or flora, for where there are no plants there are few of the worms and fishes which live on them. Thus there is but one plant that can grow at the greatest depths, and that is the *Sargasso*, of which greater quantities are found than of any other plant in the world. It floats on the water and sticks together, so that the sea at a distance resembles a green meadow, and under this are to be found the strangest creatures and mussels, or *Testacea pelagica*, which, as they successively grow up and die, drop their shells on the bottom and fill it up. Most of the Testacea in the mountain we have mentioned are the Pelagica, and they must have originated where the *Sargasso* grew, but how they have come to be in this place is a harder problem to solve. Most people say that the shells have been brought hither in the deluge, and that hence they were witnesses of this wonderful alteration of the earth. But those who say so seem to me to be very little at home in mathematics, for how could the surging waters have thrown the shells a distance of several thousand miles to a certain place and then place above them the other earth strata in such regular order? If these phenomena are sufficiently considered one must necessarily admit that the earth must have been covered by the sea, and that *Sargasso* must have grown here under which these creatures lived and died, whereupon finally, after the water had been reduced and the *Sargasso* driven away, gravel must have been cast up by the waves in new ridges on the shore and then coalesced into stone. * * *

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As has been stated above, little was known at the time in question concerning the deep-sea fauna or of the manner in which shells, mussels, and other animals are distributed on the sea bottom, and * * * it is not to be wondered at that Linné, who in this respect

was forced to rely on others, should have supposed that the shell-gravel lime (testaceous lime) was formed at great depths and was chiefly derived from pelagic forms. This rock species, as we now know, is in reality a shore formation, even if shells of pelagic forms be embedded in it. * * *

* * * After having observed at Helsingborg the shifting strata of siliceous shales and shaly sandstone contained in the high bluff east of the town * * * Linné writes:

> My mind reels when, on this height, I look down on the long ages that have flowed by like waves in the sound and have left traces of the ancient world, traces so nearly obscured that they can only whisper now that everything else has been silenced.

These words are evidences of inspiration, and it may easily be seen that if Linné had drawn his conclusions entirely from his own observations in nature, he would certainly have become a champion of the belief that those geological events of which "the stones speak" had, contrary to the prevailing opinion on the subject, required a tremendously long period of time. * * *

Fossils of Different Kinds—Belemnites—Trilobites—Place of the Trilobites in the Zoological System—Graptolites—Inclusions in Amber.

In addition to scattered notes of a paleontological nature in his travel descriptions Linné has also, aside from his already quoted work, Corallia Baltica, left descriptions of fossils, partly in the Systema Naturæ, partly in the Museum Tessinianum, and also in a special paper in the Vetenskapsakademiens Handlingar, 1759.

* * * * * * *

In the Museum Tessinianum Linné gives a fairly correct statement of the different ways in which fossils may occur. He characterizes four different groups as follows:

1. "Fossils (Fossilia)," such corals and shellfish as have lain in the ground for a long time nearly unchanged [a large part of what we now call "subfossils," but also others].

2. "Filled-up petrifactions (redintegrata)" of creatures covered with a hard shell. Upon being embedded in the earth and after the dissolution of the soft parts the cavity was filled with a sediment which has hardened into stone and which is now surrounded by the shell. These are the most common, and are found particularly in lime and chalk.

3. "Impressions (impressa)" of animals embedded in the sediment and "imprinted as in moldings." After the animal is dissolved only the impression is left. Examples: Impressions of fishes in the shales, sometimes also in sandstone.

4. "Petrifactions, perfect transsubstantiata of the interior as well as the exterior shape." Such are most fossil trees, but also "*Entrochia* and *Asteriæ columnares*" (i. e., stalked crinoids, which is saying too much for them).

* * * Of the fossils described I shall only mention one or two of the Swedish ones. The Belemnites are thus characterized:

The stone is somewhat cylindrical, but cone-shaped, and may be split lengthwise into two equal parts. It appears to have been bored through longitudinally with a coarse groove, from which numerous stone filaments extend laterally. All whole specimens have a conical depression at the root. This does not appear to be true of the filled-up petrifactions, but of the unaltered fossils, and particularly to those that are most often found loose, with none of the inclosing matrix.

In the Systema Naturæ (twelfth edition) it is added that the cavity at the base occasionally contains a conical nucleus [the phragmacone], divided by partitions in the same manner as the Nautilus, and having at its side a siphon, a fact demonstrating that even in this instance Linné attentively followed up discoveries made abroad.

His description of the brachiopod *Pentamerus conchidium* (*Helmintholithus conchidium L.*), commonly occurring on Gotland, is also of interest. He calls it the "cloven shell," and says:

We find no more than a single shell at a time, and never a pair, as is common in mussels. It seems strange that when we strike it with a hammer it always splits longitudinally into two equal parts.

* * * * * * *

Undoubtedly, however, the most interesting fossil in the Tessinian collection was the complete specimen of the trilobite named by Linné "*Entomolithus paradoxus*," a species to which Al. Brongniart later gave the name "*Paradoxides tessini*." Linné's Swedish name for it was "understone" or "wormstone of water fleas," and his description of it is as follows:

In this collection there is a species of stone from the alum pit at Dimbo in Westrogothia the like of which scarcely exists in the world. It is a pure black slate stone, as large as the whole of this (folio) page, most plainly engraved. The body is oval, anteriorly blunt and laterally divided by more than 20 folds, with as many pairs of feet at the sides, of which the hindfeet are the longest. In general form this worm seems to resemble most closely the species named "*Monoculus*," although of a kind quite unknown to us. * * * No stone nowadays keeps the naturalist more busy than this one, which is daily being collected and examined, particularly by the English, so that the diligent researches of several men may some day result in ascertaining its orgin.

* * * The figure given by Linné was rather coarsely executed ("figura nimis rudis," Dalman says), wherefore it has caused later investigators some trouble. Linné says that the reproduction is almost of natural size, while, to be more exact, the size of the figure

is about two-thirds of the original. The specimen is in the mineralogical museum of the University of Copenhagen, but according to a statement of Prof. N. V. Ussing it is said to be in a poor state of preservation and seems to be gradually approaching destruction. * * *

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During his journey in Skåne, Linné noticed in the aluminous shales at Andrarum the *Insectorum vestigia*, already described from that place by Bromell, in which the former recognized animals of the same group he had previously observed in Öland and Westrogothia, "although there as large as a fist, but here in Andrarum not larger than flies." The trilobite in question, named in the Systema Naturæ "*Entomolithus paradoxus β Cantharidium*," is the *Olenus truncatus*.

On the other hand, he found it difficult to determine the "Vermiculorum vaginipennium imagines," also occurring in this place and cited by Bromell, which, however, he later recognized as belonging to the same animal group, and introduced in the Systema Naturæ as "*Entom. parad. γ Pisiformis*," or what we now call the "*Agnostus pisiformis*."

In the Vetenskapsakademiens Handlingar, 1759, Linné contributed a special paper, accompanied with illustrations, on the fossil *Entomolithus paradoxus*, in which he included all trilobites. * * * Two of these need not arrest our attention; they are pygidia of *Calymmene punctata* and *C. blumenbachii* (according to Wahlenberg and Dalman), while the third is the most interesting. Linné says of it that it "is one of the most perfect specimens I have been able to find among many thousand fragments," and, further, after having described the thoracic shield and the somatic segments, the lateral parts of which [pleuræ] "are not feet, but an outgrowth of the shields proper," he says:

> The most peculiar feature of this specimen is, first of all, the antennæ, which we have never seen in any other, and which most plainly demonstrate that this fossil must belong to the insect genus (to which at that time the Crustacea were referred), or, to be more exact, a genus intermediate between *Cancros*, *Monoculos*, and *Oniscos*. * * *

While it is true that the specimen described by Linné, which is usually considered to be the *Parabolina spinulosa*, and at all events is an olenid, has been mentioned since that time by several of those who have investigated the trilobites, it seems that there has been a generally indifferent or skeptical attitude concerning the antennæ pointed out by Linné. When toward the end of the last century it was shown by American scientists that the trilobites actually possessed antennæ, S. L. Törnquist called attention to Linné's observation, and on this subject there arose a discussion between the former and C. E. Beecher, the American geologist, who pretended not to see a trace of antennæ

in the impressions described by Linné,[a] while, on the contrary, Törnquist continues to regard them as such. In the present status of the question a definite decision is impracticable unless the specimen described by Linné can be recovered. However, Linné's surmise that these animals possessed antennæ has, at any rate, been confirmed, and it was he who first assigned to the trilobites their true position in the zoological system of that day.

During his journey in Skåne Linné also observed graptolites, and in the description of his travels gives an illustration of them. * * * They are introduced into the Systema Naturæ (1768) as *Graptolithus scalaris*, and have since served as a type of the genus. According to S. A. Tullberg,[b] the vertical form shown in the figure is what is now termed the "*Climacograptus scalaris*," while the one spirally coiled is probably the *Monograptus triangularis*.

* * * Although Aristotle, Pliny, and Tacitus had, on the whole, a true conception of the formation of amber, diverging opinions were later expressed by Agricola (1546) and others, who believed that it had been formed in the sea. During the journey in Skåne Linné noticed amber in several places, but especially at Falsterbo. * * * In the Museum Tessinianum the following is said of amber:

> In it are often found several insects, the presence of which shows that the amber has been floating and has always been above the surface of the earth (i. e., not formed in the sea). Beetles with shells on their wings are rarely found in it.

In the Systema Naturæ it is said that the insects were incased at a time when the amber was resin or gum, and that they are not true fossils.

As a conclusion to this chapter I may appropriately quote Linné's own words on the subjects which have here been dwelt upon:

> Of what use are the great numbers of petrifactions, of different species, shape, and form which are dug up by the naturalists? Perhaps the collection of such specimens is sheer vanity and inquisitiveness. I do not presume to say; but we find in our mountains the rarest animals, shells, mussels, and corals embalmed in stone, as it were, living specimens of which are now being sought in vain throughout Europe. These stones alone whisper in the midst of general silence. * * *
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> * * * * * * *
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> The infinite number of fossils of strange and unknown animals buried in the rock strata beneath the highest mountains, animals that no man of our age has beheld, are the only evidence of the inhabitants of our ancient earth at a period too remote for any historian to trace.

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[a] S. L. Törnquist, "On the appendages of trilobites," Geological Magazine, 1896, p. 142, and Linné "On the appendage of trilobites," ibid., p. 568. C. E. Beecher, "On a supposed discovery of the antennæ of trilobites by Linné in 1759," American Geologist, Vol. 17 (1896), p. 303.

[b] S. A. Tullberg, "On the graptolites described by Hisinger and the older Swedish authors," Bihang till K. Sv. Vet. Akad. Handl., Vol. 6, No. 13. Stockholm, 1882.

Summary.

As will be seen from the above account Linné's contributions to geological science were both many sided and extensive. In assuming the existence of a definite succession of strata throughout the world he laid a foundation for stratigraphic geology which has been enlarged by Werner and other geologists of subsequent times. Linné certainly did not have, and at that period could not have had any true conception of the relative age of the other sedimentary rock species as compared with those of the Westrogothia Mountains: but this was a problem for investigators of a later period to solve. It is very interesting to notice how it gradually dawned upon him that the fossils in the Silurian strata, which he at first believed to exist in the depths of neighboring seas, were probably for the most part extinct: and the same may also be said of certain Cretaceous fossils. This circumstance seemed so remarkable to him because of the fact that at that time there existed no adequate conception of the real age of the earth. Linné, who in so many things was far ahead of his own time, seems even in this respect to have been inclined to emancipate himself from the prevailing opinion, and, as has been stated above, it was only his conviction that the Bible should be literally interpreted that prevented him from adopting a more liberal view. On the other hand, he strongly opposed the prevalent belief that the evidences of a former higher water level which were so common in Sweden, were connected with the "deluge." On the contrary he declares that he has never seen a trace of that catastrophe.

The evidences cited by him in support of this higher water level of ancient times, which are founded on his own observations, are clear and positive, * * * and he was the first naturalist to describe shore lines in the high mountains.

He always took special pains to collect data on material of economic importance, and hence also labored within the realm of applied or practical geology. It should here be remembered that although he pointed out the significance of marl in the agricultural development of Skåne, he was so far ahead of his time that a hundred years passed by before his prophecy commenced to attain its fulfillment. * * * He left a clear and concise statement of the different ways in which fossils may occur; he published an excellent description, for its time, of Gotland's fossil corals; he was the first to assign to the trilobites their true position in the zoological system of the period, and in the Museum Tessinianum and the Systema Naturæ he described a great number of fossils, many of which still retain the specific names assigned to them by him.

Linné's contributions to the sciences of geology and paleontology were consequently of such a nature and extent that each alone would have secured him a respected scientific name. These have long been overlooked because of the fact that, in spite of their great intrinsic importance, they were overshadowed by the magnificent achievements that linked his name with the biological sciences, and because of the additional fact that geology at his time did not exist as an independent science. What we have now seen, however, seems to demonstate that even geology has every reason to appreciate what Linné has done and accomplished as one of the founders of this science.

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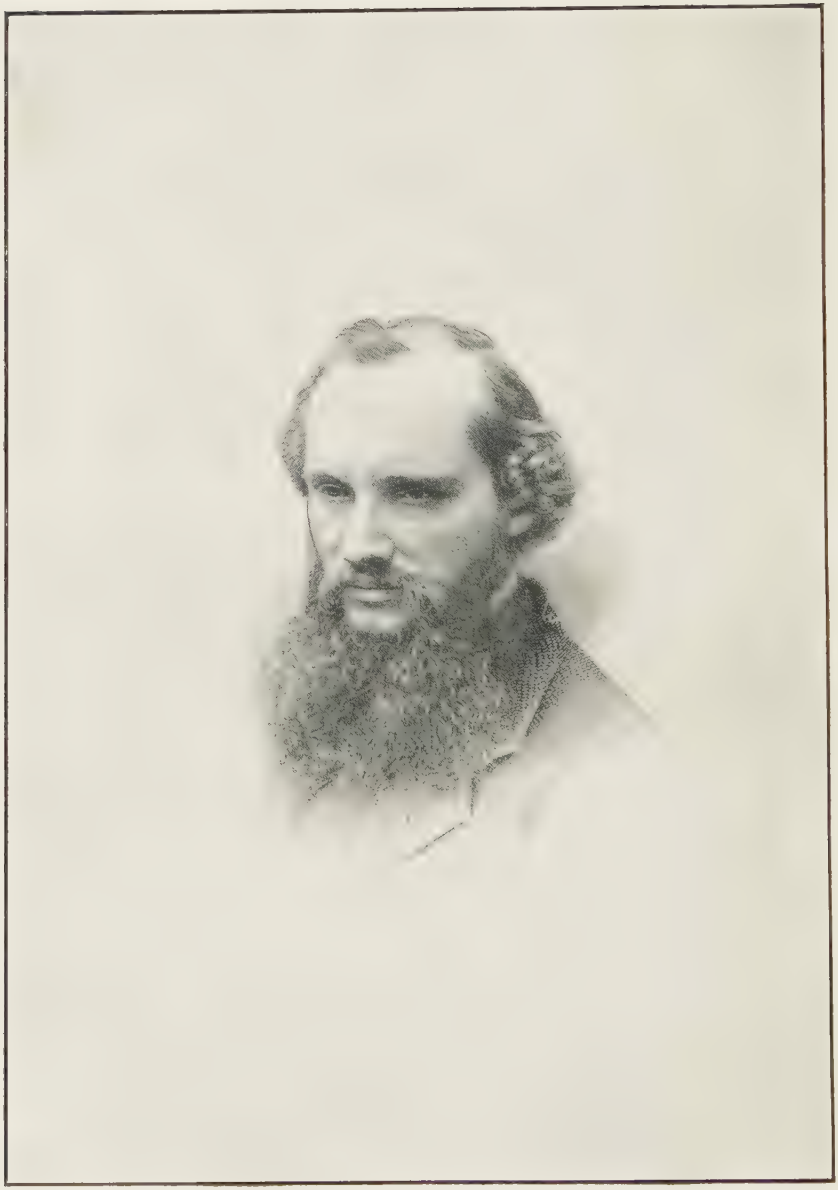


WILLIAM THOMSON, BARON KELVIN OF LARGS.

THE KELVIN LECTURE:[a] THE LIFE AND WORK OF LORD KELVIN.[b]

(With 1 plate.)

[Delivered April 30, 1908. Abridged by request and revised for the Smithsonian Institution April 6, 1909.]

By Prof. Silvanus P. Thompson, D. Sc., F. R. S.,
Past President of the Institution of Electrical Engineers.

On the 17th of December, 1907, aged 83 years, died William Thomson, Baron Kelvin of Largs.

Adequately to set forth the life and work of a man who so early won and who for so long maintained a foremost place in the ranks of science were a task that is frankly impossible. The greatness of a man of such commanding abilities and such profound influence can not rightly be gauged by his contemporaries, however intimately they may have known him. But if by the very circumstance that we have lived so near to him we are debarred from rightly estimating his greatness, we at least have the advantage over posterity that we have been able to speak with him fact to face, to learn at first hand his modes of thought, to sit at his feet as students or disciples, to marvel at his strokes of genius achieved before our very eyes, to learn to love him for his single-hearted enthusiasms, for his kindliness of soul, his unaffected simplicity of life.

But if we may not attempt the impossible, we may at least essay the task of setting down in simple fashion some account of those things which he achieved.

Let me first set down in briefest outline a sketch of his early life.

William Thomson was born on June 26, 1824, in Belfast, being the second son and fourth child of James and Margaret Thomson. James Thomson, who was at that time professor of mathematics in

[a] Founded by the Institution of Electrical Engineers (of Great Britain) in memory of the work of the Right Hon. Lord Kelvin, O. M., G. C. V. O., F. R. S., and of his connection with the institution as president in 1874, in 1889, and in 1907.

[b] Reprinted, by permission, from Journal of the Institution of Electrical Engineers, London, vol. 41, 1908, pp. 401–423.

the Royal Academic Institute of Belfast, was the son of a small farmer at Ballynahinch, in County Down, where his ancestors had settled about the year 1641 when they migrated from the lowlands of Scotland. James Thomson had early shown a taste for mathematical studies, and by study of books had mastered the art of making sundials. He had then been sent to a small school in the district to learn classics and mathematics, rising while still a youth to the position of assistant teacher. During the winters he followed the courses in the University of Glasgow, crossing back to Belfast for the summers to resume teaching at school. After thus attending Glasgow University for five years he was appointed professor of mathematics in 1815 at the Belfast Academic Institute. His eldest son, James (Lord Kelvin's elder brother), was born in 1822, and William (Lord Kelvin), as already stated, in 1824. In 1830, when William was 6 years old, his mother died. His father would never send his boys to school, but taught them himself. In 1832, when William was 8 years old, Professor Thomson was offered the chair of mathematics at Glasgow, and he with his family of six children accordingly removed from Belfast. He was in many ways a remarkable man. He made several original contributions to mathematics and produced several sound text-books, including one on the differential and integral calculus. But his range of accomplishments was wide. He was an excellent classical scholar, familiar with both Latin and Greek, and able, on occasion, to give lectures in the classics to the university students. After his removal to Glasgow he still kept the education of his sons in his own hands, and so it happened that in 1834 William Thomson, when in his eleventh year, matriculated as a student in the university without ever having been at school. He early made his mark by his progress in mathematics and physical science, and in 1840 produced an essay "On the figure of the earth," which won him the university medal. He also read Greek plays with Lushington, and moral philosophy. To the end of his life he was in the habit of bringing out quotations from the classic authors. His fifth year as a student at Glasgow (1839–40) was notable for the impulse toward physics which he received from the lectures of Prof. J. P. Nichol and from those of David Thomson (a relation of Faraday), who temporarily took the classes in natural philosophy during the illness of Professor Meikleham. In this year William Thomson had systematically studied the Mécanique Analytique of Lagrange and the Mécanique Celeste of Laplace, both mathematical works of a high order, and had made the acquaintance—a notable event in his career—of that remarkable book, Fourier's Théorie de la Chaleur. On May 1 he borrowed it from the college library. In a fortnight he had read it completely through.

The effect of reading Fourier dominated his whole career thenceforward. He took the book with him for further study during a three months' visit to Germany. During his last year (1840–41) at Glasgow he communicated to the Cambridge Mathematical Journal, under the signature "P. Q. R.," an original paper "On Fourier's expansions of functions in trigonometrical series," which was a defense of Fourier's deductions against some strictures of Professor Kelland. He left Glasgow University after six years of study, without even taking his degree, and on April 6, 1841, entered as a student at St. Peter's College, Cambridge. Here he speedily made his mark, and continued to contribute, at first anonymously, to the Cambridge Mathematical Journal, papers inspired by his studies of the higher mathematics and by his love for physics. The analogy between the movement of heat in conductors along lines of flow and across surfaces of unequal temperature, and the distribution of electricity on conductors in such a way that the lines of electric force were crossed orthogonally by surfaces of equipotential, led to his paper entitled "The uniform motion of heat in homogeneous solid bodies, and its connection with the mathematical theory of electricity." Here was an undergraduate of 17 handling methods of difficult integration readily and with mastery, at an age when most mathematical students are being assiduously drilled in so-called "geometrical conics" and other dull and foolish devices for calculus dodging. It is true he followed the courses of coaching prescribed by his tutor, Hopkins, but he could not be kept to the routine of book work and he never quite forgave Hopkins for keeping from him until the last day of his residence at Cambridge Green's rare and remarkable Essay on the Application of Mathematical Analysis to the Theories of Electricity and Magnetism. He also formed a close friendship with Stokes, then a young tutor, with whom, until his death in 1902, he maintained a continual interchange of ideas and suggestions in mathematical physics. Of Thomson's Cambridge career so much has been written of late that it may be very briefly touched here. How he went up for his Tripos in 1845; how he came out second wrangler only, being beaten by the rapid Parkinson; how he beat Parkinson in the Smith's prize competition; how he rowed for his college to save Peterhouse from being bumped by Caius in the university races of 1843; how he won the Colquohoun silver sculls; how he helped to found the Cambridge University Musical Society and played the French horn in the little orchestra, which at its first concert, on December 8, 1843, performed Haydn's First Symphony, the Overture to Masaniello, the Overture to Semiramide, the Royal Irish Quadrilles, and the Elizabethen Waltzes of Strauss! But these things—are they not written in the book of the Cambridge Chronicle?

Once when Lord Kelvin was in a chatty mood I asked him point-blank how it occurred that he was not senior wrangler. His blue eyes lighted up as he proceeded to explain that Parkinson had won principally on the exercises of the first two days, which were devoted to text-book work rather than to problems requiring analytical investigation. And then he added, almost ruefully, "I might have made up on the last two days but for my bad generalship. One paper was really a paper that I ought to have walked through, but I did very badly by my bad generalship, and must have got hardly any marks. I spent nearly all the time on one particular problem that interested me, about a spinning top being let fall on to a rigid plane—a very simple problem if I had tackled it in the right way—but I got involved and lost time on it and wrote something that was not good, and there was no time left for the other questions. I could have walked over the paper. A very good man Parkinson—I didn't know him personally at the time—who had devoted himself to learning how to answer well in examinations, while I had had, during previous months, my head in some other subjects not much examined upon—theory of heat, flow of heat between isothermal surfaces, dependence of flow on previous state, and all the things I was learning from Fourier." And then he drifted off into a talk of his early papers, and to the mathematical inference (as the result of assigning negative values to the time t) that there must have been a creation. "It was," he continued, "this argument from Fourier that made me think that there must have been a beginning. All mathematical continuity points to a beginning—this is why I stick to atoms * * * and they must have been small—smallness is a necessity of the complexity. They may have all been created as they were, complexity and all, as they are now. But we know they have a past. Trace back the past and one comes to a beginning, to a time zero beyond which the values are impossible. It's all in Fourier."

On leaving Cambridge Thomson went to Paris and worked in the laboratory of Regnault at the Collège de France. He was here four months. There was no arrangement for systematic instruction, and Thomson's principal occupation was to work the air pump to make a vacuum in one of two large glass globes which Regnault was weighing against one another in some determinations of the densities of gases. He made here the acquaintance of Biot and of Sturm and Foucault, of whom he spoke in terms of admiration. Returning, he was awarded a college fellowship of £200 a year.

Thomson was now 21 years old, but had already established for himself a growing reputation for his mastery of mathematical physics. He had published about a dozen original papers, and had gained experience in three universities. In 1846 the chair of natural

philosophy at Glasgow became vacant by the death of Professor Meikleham, and Thomson, at the age of 22, was chosen to fill it. His father, Prof. James Thomson—he died in 1849—still held the chair of mathematics, Prof. Thomas Thomson held that of chemistry, while Prof. Allen Thomson occupied the chair of anatomy. William Thomson was the youngest of the five Professors Thomson then holding office in Glasgow. He chose for the subject of his inaugural lecture: "On the distribution of heat through the earth."

This professorship he continued to hold till he resigned it in 1899, after continuous service of fifty-three years. Of his work as a university teacher this is hardly the occasion to say much; it will be fully described by his pupil and successor, Prof. Andrew Gray. The old college buildings where he lectured and worked for twenty-four years were ill-adapted for any laboratory facilities, yet he contrived to organize a physics laboratory—the first of its kind in Great Britain—in some disused rooms in a dark corner of one of the quadrangles, and enlisted the voluntary service of a number of keen students in his early experimental researches on the electrodynamic and thermoelectric properties of matter. In the lecture theater his manifest enthusiasms won for him the love and respect of all students, even those who were hopelessly unable to follow his frequent flights into the more abstruse realms of mathematical physics.

Over the earnest students of natural philosophy he exercised an influence little short of inspiration, an influence which extended gradually far beyond the bounds of his own university.

The next few years were times of strenuous work, fruitful in results. By the end of 1850, when he was 26 years of age, he had published no fewer than 50 original papers, mostly highly mathematical in character, and several of them in French. Among these researches there is a remarkable group which originated in his attendance in 1847 at the meeting of the British Association. He had prepared for reading at that meeting a paper on the exceedingly elegant process discovered by himself of treating certain problems of electrostatics by the method of electric images, a method even now not sufficiently well appreciated. But a more important event was the commencement of his friendship with Joule, whom he met here for the first time. Joule, a Manchester brewer, and honorary secretary of the Manchester Literary and Philosophical Society, had for several years been pursuing his researches on the relations between heat, electricity, and mechanical work. Incited at first by Sturgeon into investigations on the electromagnet, and on the performance of electromagnetic engines—that is, electric motors—Joule had already, in 1840, communicated to the Royal Society a paper on the "Production of heat by voltaic electricity." He had also read papers at

the British Association's meetings "On the electric origin of chemical heat," at Manchester, in 1842; "On the calorific effects of magneto-electricity" and "On the mechanical value of heat," at Cork, in 1843; "On specific heat," at York, in 1844; and "On the mechanical equivalent of heat," at Cambridge, in 1845. But at that date, when there was as yet no doctrine of conservation of energy, when scientific men were not accustomed to distinguish either in language or in fact between force and work, when "caloric" was classed with light and sound among the "imponderables," Joule's work was listened to with impatience, and his teachings fell upon deaf ears. Was he not an amateur, dabbling in science, and carried away with strange notions? For the Oxford meeting, too, Joule had prepared a paper. Its title was "On the mechanical equivalent of heat, as determined from the heat evolved by the agitation of liquids." It was relegated to an unimportant place, and would have received as little notice as its predecessors but for Thomson's intervention.

Thomson, in fact, though he at first had some difficulty in grasping the significance of the matter, threw himself heart and soul into the new and strange doctrines that heat and work were mutually convertible, and for the next six or eight years, partly in cooperation with Joule, partly independently, he set his unique powers of mind to unravel those mutual relations.

Thomson's mind was essentially metrical. He was never satisfied with any phenomenon until it should have been brought into the stage where numerical accuracy could be determined. He must measure, he must weigh, in order that he might go on to calculate.

"I often say,"[a] he once remarked, "that when you can measure what you are speaking about and express it in numbers, you know something about it; but when you can not measure it, when you can not express it in numbers, your knowledge is of a meager and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of *science*, whatever the matter may be. * * * The first step toward numerical reckoning of properties of matter, more advanced than the mere reference to a set of numbered standards, as in the mineralogist's scale of hardness, or to an arbitrary trade standard, as in the Birmingham wire-gauge, is the discovery of a continuously varying action of some kind and the means of observing it definitely and measuring it in terms of some arbitrary unit or scale division. But more is necessary to complete the science of measurement in any department, and that is the fixing on something *absolutely* definite as the unit of

[a] Lecture on "Electrical units of measurements" at Institution of Civil Engineers, May 3, 1883. Reprinted in Popular Lectures and Addresses, Vol. I, p. 73.

reckoning." It was in this spirit that Thomson approached the subject of the transformation of heat. Joule had laid down on certain lines the equivalence of heat and work, and had even measured the numerical value of the equivalent. But before him, in 1824, Carnot, though he proceeded on the fallacious assumption of the material nature of caloric, had, in his remarkable book, Réflexions sur la puissance Motrice du Feu, discussed the proportion in which heat is convertible into work, and had introduced the very valuable notion of submitting a body to a reversible cycle of operations such that, after having experienced a certain number of transformations it is brought back identically to its primitive physical state as to density, temperature, and molecular constitution. He argued, correctly, that on the conclusion of the cycle it must contain the same quantity of heat as that which it initially possessed. But he argued, quite incorrectly, that the total quantity of heat lost by the body during one set of operations must be precisely compensated by its receiving back an equal quantity of heat in the other set of operations. We can see now that this is false; for if it were true, none of the heat concerned in the cycle would be transformed into work. Those who were investigating the subject at this time, among them Clausius and Rankine, perceived this, and noted that since the steam received into the cylinder must be hotter than that expelled from it, the degree to which the transformation is successful must depend on the respective temperatures; a fact, moreover, recognized by all engineers since the date when Watt discovered the advantage of cooling the exhaust steam by a condenser. Carnot, indeed, proved that the ratio of the work done by a perfect—that is, a reversible—engine to the heat received from the source depends on the temperatures of source and condenser only; and when these temperatures are nearly equal the efficiency is expressible by the product of their difference into a certain function of either of them, called "Carnot's function." Rankine went further in pointing out that this function was greater as the temperature in question was lower. But here Thomson's exact mind seized upon the missing essential. Temperatures had hitherto been measured by arbitrary scales based on the expansion of quicksilver, or of air or other gas; and the quicksilver thermometer scale did not agree precisely with that of the air thermometer. He was not satisfied with arbitrary scales. He had this in hand even before his first meeting with Joule, and in June, 1848, communicated to the Cambridge Philosophical Society a paper "On an absolute thermometric scale founded on Carnot's theory of the motive power of heat, and calculated from Regnault's observations." In this paper he set himself to answer the question, Is there any principle on which an absolute thermo-

metric scale can be founded? He arrived at the answer that such a scale is obtained in terms of Carnot's theory, each degree being determined by the performance of equal quantities of work in letting one unit of heat be transformed in being let down through that difference of temperature. This indicates as the absolute zero of temperature the point which would be marked as −273° on the air-thermometer scale. In 1849 he elaborated this matter in a further paper on "Carnot's theory," and tabulated the values of "Carnot's function" from 1° C. to 231° C. Joule, writing to Thomson in December, 1848, suggested that probably the values of "Carnot's function" would turn out to be the reciprocal of the absolute temperatures as measured on a perfect gas thermometer, a conclusion independently enunciated by Clausius in February, 1850. Independently of Joule, Mayer and Helmholtz had been considering the same problems from a more general standpoint. Helmholtz's famous publication of 1847, Die Erhaltung der Kraft—On the Conservation of Force (meaning what we now term "energy") was chiefly concerned with the proposition, based on the denial of the possibility of perpetual motion, that in all the transformations of energy the sum total of the energies in the universe remains constant.

Thomson continued to work at the subject. He experimented on the heat developed by compression of air. He verified the singular prediction of his brother, Prof. James Thomson, of the lowering by pressure of the melting-point of ice. He gave a thermodynamic explanation of the nonscalding property of steam issuing from a high-pressure boiler. He formulated, in the years 1851 to 1854, with scientific precision, in a long communication to the Royal Society of Edinburgh, the two great laws of thermodynamics—(1) the law of equivalence discovered by Joule, and (2) the law of transformation, which he generously attributed to Carnot and Clausius. Clausius, indeed, had done little more than put into mathematical language the equation of the Carnot cycle, corrected by the arbitrary substitution of the reciprocal of the absolute temperature; but Thomson never was grudging of the fame of independent discoverers. "Questions of personal priority," he wrote, "however interesting they may be to the persons concerned, sink into insignificance in the prospect of any gain of deeper insight into the secrets of nature."[a] He gave a demonstration of the second law, founding it upon the axiom that it is impossible, by means of inanimate material agency, to derive mechanical effect from any portion of matter by cooling it below the temperature of the coldest of the surrounding objects. Further, by a most ingenious use of the integrating factor to solve the differential equation for the quantity of heat needed to alter the volume and temperature

[a] Presidential address, Brit. Ass., 1871, and Popular Lectures, Vol. II, p. 166.

of unit mass of the working substance, he gave precise mathematical proof of the theorem that the efficiency of the perfect engine working between given temperatures is inversely proportional to the absolute temperature. In collaboration with Joule he worked at the "Thermal effects of fluids in motion," the results appearing between the years 1852 and 1862 in a series of four papers in the Philosophical Transactions, and four others in the Proceedings of the Royal Society. Thus were the foundations of thermodynamics laid. This brilliant development and generalization of the subject (which had grown with startling rapidity from the moment when Helmholtz denied perpetual motion and Thomson grasped the conception of the absolute zero) did not content Thomson. He must follow its applications to human needs and the cosmic consequences it involved. And so he not only suggested the process of refrigeration by the sudden expansion of compressed cooled air, but propounded the doctrine of the dissipation of energy. If the availability of the energy in a hot body be proportional to its absolute temperature, it follows that as the earth and the sun—nay, the whole solar system itself—cool down toward one uniform level of temperature, all life must perish and all energy become unavailable. This far-reaching conclusion [a] once more suggested the question of a beginning, a question which, as already remarked, had arisen in the consideration of the Fourier doctrine of the flow of heat.

In 1852, at the age of 28, William Thomson married Margaret Crum and resigned his Cambridge fellowship. The happiness of his life was, however, shadowed by his wife's precarious health, necessitating residence abroad at various times. In the summer of 1855 they stayed at Kreutznach, from which place Thomson wrote to Helmholtz, inviting him to come to England in September to attend the British Association meeting at Glasgow. He assured Helmholtz that his presence would be one of the most interesting events of the gathering, so that he hoped to see him on this ground, but also looked forward with the greatest pleasure to the opportunity of making his acquaintance, as he had desired this ever since the Conservation of Energy had come into his hands. Accordingly, on July 29 Helmholtz left Königsberg for Kreutznach, to make the acquaintance of Thom-

[a] "There is at present in the material world a universal tendency to the dissipation of mechanical energy. Within a finite period of time past the earth must have been and within a finite period of time to come the earth must again be unfit for the habitation of man as at present constituted, unless operations have been or are to be performed which are impossible under the laws to which the known operations going on at present in the material world are subject." (Mathematical and Physical Papers, Vol. I, p. 514.)

son before his journey to England. On August 6 he wrote to Frau Helmholtz that Thomson had made a deep impression on him.

I expected to find the man, who is one of the first mathematical physicists of Europe, somewhat older than myself and was not a little astonished when a very juvenile and exceedingly fair youth who looked quite girlish came forward. He had taken a room for me close by and made me fetch my things from the hotel and put up there. He is at Kreutznach for his wife's health. She appeared for a short time in the evening, and is a charming and intellectual lady, but is in very bad health. He far exceeds all the great men of science with whom I have made personal acquaintance, in intelligence, and lucidity, and mobility of thought, so that I felt quite wooden beside him sometimes.

A year later Helmholtz again met the Thomsons at Schwalbach. Writing to his father, he described Thomson as "certainly one of the first mathematical physicists of the day, with powers of rapid invention such as I have seen in no other man." In 1860, after the death of Mrs. Helmholtz, the great German philosopher again visited Britain, staying with the Thomsons for some weeks in the island of Arran. In 1863 Helmholtz, who in the meantime had married again, came to England and visited the chief universities, and in writing to his wife gives an amusing picture of his doings.

My journey to Glasgow went off very well. The Thomsons have lately moved to live in the university buildings (the old college); formerly they spent more time in the country. He takes no holiday at Easter, but his brother James, professor of engineering at Belfast, and a nephew who is a student there, were with him. The former is a level-headed fellow, full of good ideas, but cares for nothing except engineering, and talks about it ceaselessly all day and all night, so that nothing else can be got in when he is present. It is really comic to see how the two brothers talk at one another and neither listens, and each holds forth about quite different matters. But the engineer is the most stubborn, and generally gets through with his subject. In the intervals I have seen a quantity of new and most ingenious apparatus and experiments of W. Thomson, which made the two days very interesting. He thinks so rapidly, however, that one has to get at the necessary information about the make of the instruments, etc., by a long string of questions, which he shies at. How his students understand him without keeping him as strictly to the subject as I ventured to do is a puzzle to me; still there were numbers of students in the laboratory hard at work, and apparently quite understanding what they were about. Thomson's experiments, however, did for my new hat. He had thrown a heavy metal disk into very rapid rotation, and it was revolving on a point. In order to show me how rigid it became on rotation he hit it with an iron hammer, but the disk resented this, and it flew off in one direction and the iron foot on which it was revolving in another, carrying my hat away with it and ripping it up.

But we are anticipating. Hitherto Thomson's work had been mainly in pure science; but toward the end of the fifties, while still in the midst of thermodynamic studies, events were progressing which drew him with irresistible force toward the practical applications that made him famous. Indeed, it could hardly be otherwise, seeing

that he was master in whatever he touched. Early in 1853 he had communicated to the Glasgow Philosophical Society a paper "On transient electric currents,"[a] in which he investigated mathematically the discharge of a Leyden jar through circuits possessing self-induction as well as resistance. Faraday and Reiss had observed that in certain cases the gases produced by the discharge of sparks through water consisted of mixed oxygen and hydrogen, and Helmholtz had conjectured that in such cases the spark was oscillatory. Thomson determined to test mathematically what was the motion of electricity at any instant after making contact in a circuit under given conditions. He founded his solution on the equation of energy, ingeniously building up the differential equation and then finding the integral. The result was very remarkable. He discovered that a critical relation occurred if the capacity in the circuit was equal to four times the coefficient of self-induction divided by the square of the resistance. If the capacity was less than this the discharge was oscillatory, passing through a series of alternate maxima and minima before dying out. If the capacity was greater than this the discharge was nonoscillatory, the charge dying out without reversing. This beautiful bit of mathematical analysis, which passed almost unnoticed at the time, laid the foundation of the theory of electric oscillations subsequently studied by Oberbeck, Schiller, Hertz, and Lodge, and forms the basis of wireless telegraphy. Fedderssen in 1859 succeeded in photographing these oscillatory sparks, and sent photographs to Thomson, who with great delight gave an account of them to the Glasgow Philosophical Society.

At the Edinburgh meeting of the British Association in 1854 Thomson read a paper "On mechanical antecedents of motion, heat, and light." Starting with some now familiar, but then novel, generalities about energy, potential and kinetic, and about the idea of stores of energy, the author touched on the source of the sun's heat and the energy of the solar system, and then reverted to his favorite argument from Fourier, according to which, if traced backward, there must have been a beginning to which there was no antecedent. This was a nonmathematical exposition of work which, as his notebooks show, had been going on from 1850 in a very stiff mathematical form in which Fourier's equations for the flow of heat in solids were applied to a number of outlying problems involving kindred mathematics, including the diffusion of fluids and the diffusion or transmission of electric signals through long cables. The Proceedings of the Royal Society for 1854 contain the investigation of cables under the title "On the theory of the electric telegraph." Faraday had

[a] Proc. Glasgow Philos. Soc., January, 1853; Phil. Mag., June, 1853; and Mathematical and Physical Papers, Vol. I, p. 534.

predicted that there would be retardation of signals in cables owing to the coating of gutta-percha acting like the glass of a Leyden jar. Forming the required differential equation and applying Fourier's integration of it, Thomson drew the conclusion that the time required for the current at the distant end to reach a stated fraction of its steady value would be proportional both to the resistance and to the capacity; and as both of these are proportional to the length of the cable, the retardation would be proportional to the square of the length. This is the famous law of squares about which so much dispute arose. This was followed by a further research "On peristaltic induction of electric currents," communicated to the British Association in 1855, and afterwards in more complete mathematical form to the Royal Society.

Submarine telegraphy was "in the air." John and Jacob Brett had pioneered the project for a Dover-Calais cable, and in 1851 Crampton successfully united England and France. In 1853 Holyhead and Howth were connected by Mr. (later Sir) Charles Bright. And these were followed by the Dover-Ostend and longer cables. Atlantic telegraphy became the dream of the telegraph engineer. Cyrus W. Field, in 1856, negotiated a cable across the Gulf of St. Lawrence, thus connecting Newfoundland to the American continent. The Atlantic Telegraph Company was formed, with capital mostly subscribed in England, to promote the great enterprise to join Ireland to Newfoundland. Field, Brett, Bright, Statham, and Wildman Whitehouse were the chief promoters. Bright was engineer. Whitehouse (a retired medical man) electrician. In a pamphlet issued by the company, in July, 1857, narrating the preliminary proceedings, the names of John Pender, of Manchester, and Professor Thomson, of "2, The College, Glasgow," are included in the list of directors; and the statement is made that "the scientific world is particularly indebted to Prof. W. Thomson, of Glasgow, for the attention he had given to the theoretical investigation of the conditions under which electrical currents move in long insulated wires, and Mr. Whitehouse has had the advantage of this gentleman's presence at his experiments, and counsel, upon several occasions, as well as the gratification resulting from his countenance and cooperation as one of the directors of the company." This is one side of the matter. The other side is that Mr. Whitehouse had, at the British Association meeting in 1856, read a paper challenging the law of squares, and declaring that if it was true Atlantic telegraphy was hopeless. He professed to refute it by experiments, the true significance of which was disposed of by Thomson in two letters in The Athenæum. He pointed out that success lay primarily in adequate section of conductor, and hinted at a remedy (deduced from

Fourier's equations), which he later embodied in the curb signal transmitter, namely, that the coefficient of the simple harmonic term in the expression for the electrical potential shall vanish. In December, 1856, he described to the Royal Society his plan for receiving messages, namely, a sort of Helmholtz tangent galvanometer, with copper damper to the suspended needle, the deflections being observed by watching through a reading telescope the image of a scale reflected from the polished side of the magnet or from a small mirror carried by it. As we all know, he abandoned this subjective method for the objective plan in which a spot of light from a lamp is reflected by the mirror upon a scale. There is a pretty story—which is believed to be true—that the idea of thus using the mirror arose from noticing the reflection of light from the monocle which, being short-sighted, he wore hung around his neck with a ribbon.

The story of the Atlantic cable, of the failure of 1857, of the brief success of 1858, has so often been told that it need not be emphasized here. Thomson, after the failure of the first attempt, was called upon to take a more active part. He had discovered to his surprise that the conductivity of copper was greatly affected—to an extent of 30 or 40 per cent—by its purity. So he organized a system of testing conductivity at the factory where the additional lengths were being made, and was put in charge of the test room on board the *Agamemnon* in 1858. Whitehouse was unable to join the expedition, and Thomson, at the request of the directors, undertook the post of electrician in charge, without any recompense, though the tax on his time and energies was very great.

Sir Charles Bright has given us the following little silhouette of Thomson:

> As for the professor * * *, he was a thorough good comrade, good all round, and would have taken his "turn at the wheel" (of the paying-out brake) if others had broken down. He was also a good partner at whist when work wasn't on; though sometimes, when momentarily immersed in cogibundity of cogitation, by scientific abstraction, he would look up from his cards and ask, "Wha played what?"

After various disheartening mishaps success crowned their efforts. Throughout the voyage Thomson's mirror galvanometer had been used for the continuity tests and for signaling to shore, with a battery of 75 Daniell cells. The continuity was reported perfect, and the insulation had improved on submersion. On August 5 the cable was handed over to Mr. Whitehouse and reported to be in perfect condition. Whitehouse at once abandoned the Thomson mirror instruments and began working with his own patented apparatus using heavy relays and a special transmitter with induction coils. He sent in no report to the directors for a week, while he made ineffectual

attempts with bigger induction coils to get his apparatus to work. After more than a week the reflecting galvanometer and ordinary Daniell cells were resumed, and then clear messages were interchanged and international congratulations. News of peace with China and of the end of the Indian mutiny was transmitted; but the insulation was found to be giving way, and on October 20, after 732 messages had been conveyed, the cable spoke no more. It had been destroyed by Whitehouse's bungling use of induction coils, some 5 feet long, working at some 2,000 volts!

Of the part played by Thomson in the next eight years, in preparation for the cables of 1865 and 1866, there is not time to speak. Suffice it to say that throughout the preparations, the preliminary trials, the interrupted voyage of 1865, when 1,000 miles were lost, the successful voyage of 1866, when the new cable was laid and the lost one recovered from the ocean and completed, Thomson was the ruling spirit whose advice was eagerly sought and followed. On his return he was knighted for the part he played so well. He had in the meantime made further improvements in conjunction with Cromwell Varley. In 1867 he patented the siphon recorder, and, in conjunction with Fleeming Jenkin, the curb transmitter. He was consulted on practically every submarine-cable project from that time forth.

Thomson's activities during the sixties were immense. Beside all this telegraphic work he was incessant in research. He had undertaken serious investigations on the conductivity of copper. He was urging the application of improved systems of electric measurement and the adoption of rational units. When in 1861 Sir Charles Bright and Mr. Latimer Clark proposed names for the practical units based on the centimeter-gram-second absolute system, Sir William Thomson gave a cordial support; and on his initiative was formed the famous committee of electrical standards of the British Association, which year by year has done so much to carry to perfection the standards and the methods of electrical measurement. He was largely responsible for the international adoption of the system of units by his advocacy of them at the Paris congress in 1881 and in subsequent congresses. He was an uncompromising advocate of the metric system, and lost no opportunity of denouncing the "absurd, ridiculous, time-wasting, brain-destroying British system of weights and measures." His lecture in 1883 at the Civil Engineers may be taken as a summary of his views, and it gives a glimpse of his mental agility. So early as 1851 he had begun to use the absolute system, stimulated thereto by the earlier work of Gauss and Weber. The fact that terrestrial gravity varies at different regions of the earth's surface by as much as half of 1 per cent compelled the use of absolute methods where any greater accuracy than this is required. "For

myself," he said, "what seems the shortest and surest way to reach the philosophy of measurement—an understanding of what we mean by measurement, and which is essential to the intelligent practice of the mere art of measuring—is to cut off all connection with the earth." And so he imagined a traveler with no watch or tuning fork or measuring rod wandering through the universe trying to recover his centimeter of length and his second of time and reconstructing thereupon his units and standards from the wave length of the yellow light of sodium and the value of v the velocity of light from experiments on the oscillations in the discharge of a Leyden jar! Some of us in this very room remember how we listened amazed to this characteristic and bewildering excursus.

Among the activities of these fruitful years was a long research on the electrodynamic qualities of metals—thermoelectric, thermoelastic, and thermomagnetic. These formed the subject of his Bakerian lecture of 1856, which occupies no fewer than 118 pages of the reprinted Mathematical and Physical Papers. He worked hard also at the mathematical theory of magnetism. Faraday's work on diamagnetism had appeared while Thomson was a student at Cambridge. It established the fact that magnetic forces were not mere actions at a distance between supposed poles, but actions dependent on the surrounding medium; and Thomson set himself to investigate the matter mathematically. Faraday and Fourier had been the heroes of Thomson's youthful enthusiasm; and, while the older mathematicians shook their heads at Faraday's heretical notion of curved lines of force, Thomson had, in 1849 and 1850, developed a new theory with all the elegance of a mathematical disciple of Poisson and Laplace, discussing solenoidal and lamellar distributions by aid of the hydrodynamic equation of continuity. To Thomson we owe the terms "permeability" and "susceptibility," so familiar in the consideration of the magnetic properties of iron and steel. He continued to add to and revise this work through the sixties and seventies.

In 1859–60 Thomson was studying atmospheric electricity, writing on it in Nichol's Cyclopedia and lecturing on it at the Royal Institution. For this study he invented the water-dropping collector, and vastly improved the electrometer, which developed into the elaborate forms of the quadrant instrument and other types described in the B. A. report of 1867. During this work he discovered the fact that the sudden charge or discharge of a condenser is accompanied by a sound. He also measured electrostatically the electromotive force of a Daniell cell, and investigated the potentials required to give sparks of different lengths in the air.

In the winter of 1860–61 Thomson met with a severe accident. He fell on the ice when engaged at Largs in the pastime of curling and

broke the neck of his thigh. For several months he had to lie on his back; and it was at this time that he adopted the famous green note-books, which ever afterwards were the companions of his days. The accident left him with a slight limp for the rest of his life.

An admirable picture of Lord Kelvin as he was in the sixties, moving among his students and incessant in his researches, has been given in The Times of January 8, 1908, by Professor Ayrton, who was then working at Glasgow. In these years Thomson was also writing on the secular cooling of the earth and investigating the changes of form during rotation of elastic spherical shells. And as if this were not enough to have had in hand, he embarked with his friend, Professor Tait, on the preparation of a text-book of natural philosophy. There was at that date no satisfactory work to put into the hands of students, and he must supply the need. At first a short pamphlet of propositions on statics and dynamics, culled by Prof. John Ferguson from mere lecture notes, was printed for the use of students. Thomson had told Helmholtz of his purpose, and in 1862 Helmholtz wrote him:

> Your undertaking to write a text-book of natural philosophy is very praiseworthy, but will be exceedingly tedious. At the same time I hope it will suggest ideas to you for much valuable work. It is in writing a book like that that one best appreciates the gaps still left in science.

The first volume of Thomson and Tait's Treatise on Natural Philosophy was published in 1867, the second only in 1874; when it appeared that Helmholtz's hopes were just. For in approaching the subject of elasticity the gaps still left were found to be such that whole new mathematical researches were necessary before Volume I could be finished. Thomson's contributions to the theory of elasticity are no less important than those he made to other branches of physics. In 1867 he communicated to the Royal Society of Edinburgh his famous paper "On vortex atoms." Helmholtz had published a mathematical paper on the hydrodynamic equations of vortex motion, proving that closed vortices could not be produced in a liquid perfectly devoid of internal friction. Thomson seized on this idea. If no such vortex could be artificially produced, then if such existed it could not be destroyed. But being in motion and having the inertia of rotation, it would have elastic and other properties. He showed that vortex rings (like smoke rings in air) in a perfect medium are stable, and that in many respects they possess the qualities essential to the properties of material atoms—permanence, elasticity, and power to act on one another through the medium at a distance. The different kinds of atoms known to the chemist as elements were to be regarded as vortices of different degrees of complexity. Though he seemed at the end of his life to doubt whether the vortex-atom

hypothesis was adequate to explain all the properties of matter, the conception remains to all time a witness to his extraordinary powers of mind.

In 1870 Lady Thomson, whose health had been failing for several years, died. In the same year the University of Glasgow was removed from the site it had occupied for over four centuries to the new and splendid buildings on Gilmore Hill, overlooking the Kelvin River. Sir William Thomson had a house here in the terrace assigned for the residences of the professors, adjoining his laboratory and lecture room. From his youth he had been fond of the sea, and had early owned boats of his own on the Clyde. For many years his sailing yacht, the *Lalla Rookh*, was conspicuous, and he was an accomplished navigator. His experiences in cable laying had taught him much, and in return he was now to teach science in navigation. First he reformed the mariner's compass, lightening the moving parts to avoid protracted oscillations and to facilitate the correction of the quadrantal and other errors arising from the magnetism of the ship's hull. At first the Admiralty would have none of it. But the compass is now all but universally adopted both in the navy and in the mercantile marine.

Dissatisfied with the clumsy appliances used in sounding, when the ship had to be stopped before the sounding line could be let down, he devised the now well-known apparatus for taking flying soundings by using a line of steel piano wire. He had great faith in navigating by use of sounding line, and once told me—apropos of a recent wreck near the *Lizard*, which he declared would have been impossible had soundings been regularly taken—how in a time of a continuous fog he brought his yacht all the way across the Bay of Biscay into the Solent, trusting to soundings only. He also published a set of tables for facilitating the use of Sumner's method at sea. He was vastly interested in the question of the tides, not merely as a sailor, but because of the interest attending their mathematical treatment in connection with the problems of the rotation of spheroids, the harmonic analysis of their complicated periods by Fourier's methods, and their relation to hydrodynamic problems generally. He invented the tide-predicting machine, which will predict for any given port the rise and fall of the tides, which it gives in the form of a continuous curve recorded on paper, the entire curves for a whole year being inscribed by the machine automatically in about four hours. Further than this, adopting a beautiful mechanical integrator, the device of his ingenious brother, Prof. James Thomson, he invented a harmonic analyzer—the first of its kind—capable not only of solving differential equations of any order, but of analyzing any given periodic curve and exhibiting the values of the coefficients of the

various terms of the Fourier series. Wave problems always had a fascination for him, and the work of the mathematicians Poisson and Cauchy on the propagation of wave motion were familiar studies. In his lectures he used to say, "The great struggle of 1815"—and then paused, while his students, thinking of Waterloo, began to applaud—"was not that fought out on the plains of Belgium, but who was to rule the waves, Cauchy or Poisson." In 1871 Helmholtz went with Sir William Thomson on the yacht *Lalla Rookh* to the races at Inverary, and on some longer excursions to the Hebrides. Together they studied the theory of waves, "which he loved," says Helmholtz, "to treat as a race between us." Returning, they visited many friends. "It was all very friendly," wrote Helmholtz, "and unconstrained. Thomson presumed so much on his intimacy with them that he always carried his mathematical notebook about with him, and would begin to calculate in the midst of the company if anything occurred to him, which was treated with a certain awe by the party." He possessed, indeed, the faculty of detachment, and would settle quietly down with his green book, almost unconscious of things going on around him. On calm days he and Helmholtz experimented on the rate at which the smallest ripples on the surface of the water were propagated. Almost the last publications of Lord Kelvin were a series of papers on "Deep-Sea Ship Waves," communicated between 1904 and 1907 to the Royal Society of Edinburgh.

In 1874, on June 17, Sir William Thomson married Miss Frances Anna Blandy, of Madeira, whom he had met on cable-laying expeditions. Lady Kelvin, who survives him, became the center of his home in Glasgow and the inseparable companion of all his later travels. He built at Netherhall, near Largs, a beautiful mansion in the Scottish baronial style; and though he latterly had a London house in Eaton Place, Netherhall was the home to which he retired when he withdrew from active work in the University of Glasgow.

Throughout the seventies and eighties Sir William Thomson's scientific activities were continued with untiring zeal. In 1874 he was elected president of the Society of Telegraph Engineers, of which, in 1871, he had been a foundation member and vice-president. In 1876 he visited America, bringing back with him a pair of Graham Bell's earliest experimental telephones. He was president of the Mathematical and Physical Section of the British Association of that year at Glasgow.

Among the matters that can not be omitted in any notice of his life was Lord Kelvin's controversy with the geologists. He had from three independent lines of argument inferred that the age of the earth could not be infinite, and that the time demanded by the geologists and biologists for the development of life must be finite. He

himself estimated it at about a hundred million of years at the most. In vain did the naturalists, headed by Huxley, protest. He stuck to his propositions with unrelaxing tenacity but unwavering courtesy. "Gentler knight never broke lance" was Huxley's dictum of his opponent. His position was never really shaken, though the later researches of Perry, and the discovery by Strutt of the degree to which the constituent rocks of the earth contain radioactive matter, the disgregation of which generates internal heat, may so far modify the estimate as to increase somewhat the figure which he assigned.

The completion of the second edition of Vol. I of the Thomson and Tait Treatise—no more was ever published—and the collection of his own scattered researches, was a work extending over some years. In addition he wrote for the Encyclopædia Britannica, of 1879, the long and important articles on "Elasticity" and "Heat."

In 1871 he was president of the British Association at its meeting in Edinburgh. In his Presidential Address, which ranged luminously over the many branches of science within the scope of the association, he propounded the suggestion that the germs of life might have been brought to the earth by some meteorite.

With the advent of electric lighting at the end of the seventies Thomson's attention was naturally attracted to this branch of the practical applications of science. He never had any prejudice against the utilization of science for practical ends. He wrote:

> There can not be a greater mistake than that of looking superciliously upon practical applications of science. The life and soul of science is its practical application; and just as the great advances in mathematics have been made through the desire of discovering the solution of problems which were of a highly practical kind in mathematical science, so in physical science many of the greatest advances that have been made from the beginning of the world to the present time have been made in the earnest desire to turn the knowledge of the properties of matter to some purpose useful to mankind.

And so he scorned not to devise instruments and appliances for commercial use. His electrometers, his galvanometers, his siphon recorders, and his compasses had been made by James White, optician, of Glasgow. In this firm he became a partner, taking the keenest commercial interest in its operations, and frequenting the factory to superintend the construction of apparatus. New measuring instruments were required. He set himself to devise them, designing potential galvanometers, ampere gauges, and a whole series of standard electric balances for electrical engineers.

Lord Kelvin's patented inventions were very numerous. Without counting in those since 1900, taken mostly in the name of Kelvin and James White, they number 56. Of these 11 relate to telegraphy, 11 relate to compasses and navigation apparatus, 6 relate to dynamo machines or electric lamps, 25 to electric measuring instruments, 1

to the electrolytic production of alkali, and 2 to valves for fluids. He was an independent inventor of the zigzag method of winding alternators, which the public knew under the name of Ferranti's machine, which was manufactured under royalties payable to him. He was interested even in devising such details as fuses and the suspension pulleys with differential gearing by which incandescent lamps can be raised or lowered.

He gave evidence before a parliamentary committee on electric lighting and discussed the theory of the electric transmission of power, pointing out the advantage of high voltages. The introduction into England in 1881 of the Faure accumulator excited him greatly. In his Presidential Address to the Mathematical and Physical Section of the British Association at York that year he spoke of this and of the possibility of utilizing the powers of Niagara. He also read two papers, in one of which he showed mathematically that in a shunt dynamo best economy of working was attained when the resistance of the outer circuit was a geometric mean between the resistances of the armature and of the shunt. In the other he laid down the famous law of economy of copper lines for the transmission of power.

Helmholtz, visiting him again in 1884, found him absorbed in regulators and measuring apparatus for electric lighting and electric railways. "On the whole," Helmholtz wrote, "I have an impression that Sir William might do better than apply his eminent sagacity to industrial undertakings; his instruments appear to me too subtle to be put into the hands of uninstructed workmen and officials. * * * He is simultaneously revolving deep theoretical projects in his mind, but has no leisure to work them out quietly. As far as that goes, I am not much better off." But he shortly added, "I did Thomson an injustice in supposing him to be wholly immersed in technical work; he was full of speculations as to the original properties of bodies, some of which were very difficult to follow; and, as you know, he will not stop for meals or any other consideration." And, indeed, Thomson had weighty things in his mind. He was revolving over the speculations which later in the same year he was to pour out in such marvelous abundance in his famous 20 lectures in Baltimore "On molecular dynamics and the wave theory of light." These lectures, delivered to 26 hearers, mostly accomplished teachers and professors, were reported verbatim at the time and reprinted by him with many revisions and additions in 1904. Of this extraordinary work, done at the age of 60, it is difficult to speak. Day after day he led the 26 "coefficients" who sat at his feet through the mazes of solid-elastic theory and the spring-shell molecule, newly invented in order to give a conception how the molecules of matter are related to the ether through which light waves are propagated. All his life he had been endeavoring to discover a rational mechanical explanation for the

most recondite phenomena—the mysteries of magnetism, the marvels of electricity, the difficulties of crystallography, the contradictory properties of ether, the anomalies of optics. While Thomson had been seeking to explain electricity and magnetism and light dynamically, or as mechanical properties, if not of matter, at least of molecules, Maxwell (the most eminent of his many disciples) had boldly propounded the electromagnetic theory of light and had drawn all the younger men after him in acceptance of the generalization that the waves of light were essentially electromagnetic displacements in the ether. Thomson had never accepted Maxwell's theory. It is true that in 1888 he gave a nominal adhesion, and in the preface which, in 1893, he wrote to Hertz's Electric Waves, he himself uses the phrase "the electromagnetic theory of light, or the undulatory theory of magnetic disturbance." But later he withdrew his adhesion, preferring to think of things in his own way. Thomson's Baltimore lectures, abounding, as they do, in brilliant and ingenious points, and ranging from the most recondite problems of optics to speculations on crystal rigidity, the tactics of molecules and the size of atoms, leave one with the sense of being a sort of protest of a man persuaded against his own instincts and struggling to find new expression of his thoughts so as to retain his old ways of regarding the ultimate dynamics of physical nature.

One characteristic of all Lord Kelvin's teaching was his peculiar fondness for illustrating recondite notions by models. Possibly he derived this habit from Faraday; but he pushed its use far beyond anything prior. He built up chains of spinning gyrostats to show how the rigidity derived from the inertia of rotation might illustrate the property of elasticity. The vortex-atom presented a dynamical picture of an ideal material system. He strung together little balls and beads with sticks and elastic bands to demonstrate crystalline dynamics. On the use of the model to illustrate physical principles he spoke as follows at Baltimore:

> My object is to show how to make a mechanical model which shall fulfill the conditions required in the physical phenomena that we are considering, whatever they may be. At the time when we are considering the phenomena of elasticity in solids I shall want a model of that. At another time, when we have vibrations of light to consider, I shall want to show a model of the action exhibited in that phenomenon. We want to understand the whole about it; we only understand a part. It seems to me that the test of "Do we or do we not understand a particular subject in physics?" is "Can we make a mechanical model of it?" I have an immense admiration for Maxwell's mechanical model of electromagnetic induction.

And again Lord Kelvin says:

> I never satisfy myself until I can make a mechanical model of a thing. If I can make a mechanical model, I can understand it. As long as I can not make a mechanical model all the way through I can not understand it.

This use of models has become characteristic of the tone and temper of British physicists. Where Poisson or Laplace saw a mathematical formula, Kelvin, with true physical imagination, discerned a reality which could be roughly simulated in the concrete. And throughout all his mathematics his grip of the physical reality never left him. According to the standard that Kelvin set before him, it is not sufficient to apply pure analysis to obtain a solution that can be computed. Every equation, "every line of the mathematical process must have a physical meaning, every step in the process must be associated with some intuition; the whole argument must be capable of being conducted in concrete physical terms."[a] In other words, Lord Kelvin, being a highly accomplished mathematician, used his mathematical equipment with supreme ability as a tool; he remained its master and did not become its slave.

Once Lord Kelvin astonished the audience at the Royal Institution by a discourse on "Isoperimetrical problems," endeavoring to give a popular account of the mathematical process of determining a maximum or minimum, which he illustrated by Dido's task of cutting an oxhide into strips so as to inclose the largest piece of ground; by Horatius Cocles's prize of the largest plot that a team of oxen could plow in a day; and by the problem of running the shortest railway line between two given points over an uneven country. On another occasion he entertained the Royal Society with a discourse on the "Homogeneous partitioning of space," in which the fundamental packing of atoms was geometrically treated, affording incidentally the theory of the designing of wall-paper patterns.

To the last Lord Kelvin took an intense interest in the most recent discoveries. Electrons—or "electrions," as he called them—were continually under discussion. He prided himself that he had read Rutherford's book on Radio-activity again and again. He objected, however, in toto to the notion that the atom was capable of division and disintegration. In 1903, in a paper called "Aepinus atomized," he reconsidered the views of Aepinus and Father Boscovich from the newest standpoint, modifying Aepinus's theory to suit the notion of electrons.

After taking part in the British Association meeting of 1907 at Leicester, where he entered with surprising activity into the discussions of radio-activity and kindred questions, he went to Aix les Bains for change. He had barely reached home at Largs in September when Lady Kelvin was struck down with a paralytic seizure. Lord Kelvin's misery at her hopeless condition was intense. He had himself suffered for fifteen years from recurrent attacks of facial neuralgia, and in 1906 underwent a severe operation. Under these

[a] Prof. A. E. H. Love.

afflictions he had visibly aged, and the illness of Lady Kelvin found him little able physically to sustain the anguish of the stroke. He wandered distractedly about the corridors of his house, unable at last to concentrate his mind on the work at hand. A chill seized him, and after about a fortnight of prostration he sank slowly and quietly away.

He was buried in Westminster Abbey, with national honors, on December 23, 1907.

The sympathies of all of us go out to the gracious lady who survives him and who with such assiduous devotion tended him in his declining years.

Honors fell thickly on Lord Kelvin in his later life. He was President of the Royal Society from 1890 to 1894. He had been made a Fellow of the Royal Society in 1851 and in 1883 had been awarded the Copley medal. He was raised to the peerage in 1892. He was one of the original members of the Order of Merit, founded in 1902; was a grand officer of the Legion of Honor; and held the Prussian order Pour le Mérite; in 1902 was named a privy councilor. In 1904 he was elected chancellor of the university, in which he had filled the chair of natural philosophy for fifty-three years. He had celebrated his jubilee with unusual marks of world-wide esteem in 1896, and finally retired in 1899. He was a member of every foreign academy, and held honorary degrees from almost every university. In 1899 we elected him an honorary member of our institution.

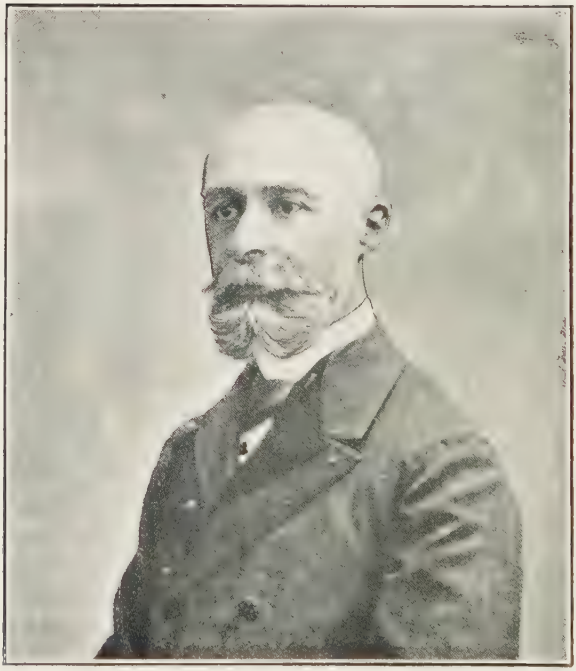
In politics he was, up to 1885, a broad Liberal: but, as was natural in an Ulsterman, became an ardent Unionist on the introduction of the home-rule bill. He once told me that he preferred Chamberlain's plan of home rule with four Irish parliaments—one in each province.

In religion Lord Kelvin was an Anglican—at least from his Cambridge days, but when at Largs attended the Presbyterian Free Church. His simple, unobtrusive, but essential piety of soul was unclouded. He had a deep detestation of ritualism and sacerdotalism, which he hated heart and soul in all its forms; and he denounced spiritualism as a loathsome and vile superstition. His profound studies had led him again and again to contemplate a beginning to the order of things, and he more than once publicly professed a profound and entirely unaffected belief in Creative Design.

Kindly hearted, lovable, modest to a degree almost unbelievable, he carried through life the most intense love of truth and an insatiable desire for the advancement of natural knowledge. Accurate and minute measurement was for him as honorable a mode of advancing knowledge as the most brilliant or recondite speculation. At both ends of the scale his preeminence in the quest for truth was un-

challenged. If he could himself at the end of his long career describe his own efforts as "failure," it was because of the immensely high ideal[a] which he set before him. "I know," he said on the day of his jubilee, "no more of electric and magnetic force, or of the relation between ether, electricity, and ponderable matter, or of chemical affinity, than I knew and tried to teach to my students in my first session." Yet which of us has not learned much of these things because of his work? We of this Institution of Electrical Engineers may well be proud of him—proud that he was one of our first members, that he was thrice our president, and that as our president he died. We shall not look upon his like again.

[a] He conceived the possibility of formulating a comprehensive molecular theory, definite and complete, "in which all physical science will be represented with every property of matter shown in dynamical relation to the whole." Presidential Address to the British Association, 1871, reprinted in Popular Lectures and Addresses, Vol. II, p. 163.



HENRI BECQUEREL.

THE WORK OF HENRI BECQUEREL.[a]

(With 1 plate.)

By André Broca.

INTRODUCTION.

It is no small nor easy task to retrace the life of Henri Becquerel, unveiling his inner life and showing how in a life consecrated to daily labor, moment by moment, he accumulated the great mass of scientific material which, in his thirtieth year, opened to him the doors of the Académie des Sciences, and how finally, through the logical development of his train of thought, he reached the discovery which has immortalized his name.

It was an instructive spectacle to see Becquerel in his laboratory arranging his apparatus with consummate skill, often constructing it from odd pieces of card or of copper wire, which seemed alive under his fingers, and with which he made the discoveries which form his memoirs. Foreign scientists who came in throngs to see each new experiment could scarcely believe a laboratory so barren could yield so abundant a harvest. They were astonished and charmed at their reception, so simple and cordial, where they awaited the formal dignity of a man so eminent. The laboratory seemed his normal place. Experimental research, in the accomplishment of which he braved every difficulty, seemed to be in him a vertiable physiological function.

Becquerel made physics from all that fell under his hands. He was raised for physics and by a physicist. The most precious memories, and with which he often entertained his friends, were of his father and grandfather, whose discourse and example had helped to shape his mind. In his youth the great reward for his vacation days was to enter the laboratory of his father and see the old or new experiments, to perform those within his ability, fashioning the apparatus with his own hands. One of his most vivid recollections was seeing his father come in one noon from his laboratory to announce

[a] Translated, by permission, from Revue générale des Sciences pures et appliquées. Paris, 19th year, No. 20, October 30, 1908.

to his grandfather the invention of the phosphoroscope, discussing it and its results, which the following day more than verified.

Becquerel recounted these circumstances with no boastful spirit, but rather to attribute to his up-bringing much of his success. He had the joy of seeing his son enter with distinction the same career and to be able to transmit what had been his own heritage. Although trained in science, his artistic tastes were not undeveloped. In painting he was an enlightened connoisseur, owing this trait to his ancester, Girodet, of whom he possessed some masterpieces, among others admirable drawings, which he liked to show to his friends and whose beauty he appreciated.

His morals were of the highest, and he had a horror of all duplicity and deceit. He had for all questions the broadest and most enlightened tolerance. That spirit whose every effort strove for the attainment of scientific truth knew how to avoid the lure of insufficient evidence. While holding a clear-cut personal opinion, he was always tolerant of any opinion of others having for its purpose the elevation of morals.

This explains how he entered the École Polytechnique at 19, in 1873; how from there he entered the Ponts-et-chausées and published his first work at 22 years of age, in the year following his graduation from the École Polytechnique. From then until his death he never ceased to publish works more and more remarkable. The École Polytechnique made him a lecturer in physics while he was yet only an engineering student in order to give him the place as professor upon the retirement of Potier, and the museum judged him worthy of holding the chair already made illustrious by his father and grandfather and held before them by Guy-Lussac. Merited honors have never ceased to be his recompense; he was a member of the more renowned foreign scientific bodies, the Royal Society of London, the Academy of Berlin, the Académie Royale dei Lincei, the National Academy of Washington. He received the medals and prizes held in the highest esteem—the Rumford prize of London, in 1900; the Helmholtz medal of Berlin, in 1901; the Nobel prize, in 1903; the Barnard medal of the United States, in 1903. The Académie des Sciences made him its president in 1908, and at the same time the Société Française de Physique bestowed upon him the widely coveted title of "honorary member," and at the death of Lapparent he was almost unanimously named its permanent secretary. He was but 55 and seemed destined to long hold this worthy honor when death cruelly snatched him away but a few weeks after he received it.

Before a blow so cruel it is useless to express our regrets. The homage due such a man and worthy of the memory which his own family, his friends, scientists, and the whole world will retain is to retrace as fully as is possible the history of his scientific achievements.

HENRI BECQUEREL BEFORE RADIO-ACTIVITY.

The problems which preoccupied Becquerel during his entire life related to the constitution of matter and the manner in which this reacts upon the magnetic and optical properties of bodies. He approached the problem through rotary magnetic polarization and his theories led him to laws of primordial importance. He was the first to admit that in molecular phenomena there must be a partial carrying along of the ether by matter, and from this hypothesis he deduced the formula—

$$\frac{R}{n^2\,(n^2-1)} = \text{constant},$$

where R is the rotation of the plane of polarization and n the index of refraction. Experiment showed this true for bodies, group by group, and while not wholly verifying the theory yet it indicated that he was on the right path and pointed the way for further progress.

The next step was the study of rotary magnetic dispersion. Verdet had shown that the rotation is nearly proportional to the square of the wave length and that the product of the rotation by the square of the wave length slowly increases from the less to the more refrangible radiations. Becquerel divided these results by the factor $n^2\ (n^2-1)$, and the result became very nearly constant, indicating how closely his theory as to the connection of ether and matter was connected with these phenomena.

Verdet noted that in magnetic media the rotation of the plane of polarization is inverse to that in diamagnetic bodies, and that consequently there is a difference between magnetism and diamagnetism. For Edmond Becquerel it did not seem so; he believed, rather, that diamagnetic bodies were less magnetic than the vacuum; magnetic ones more so. Henri Becquerel tried to show that the phenomena supported his father's views. He verified the observations of Verdet, but he showed further that magnetic and diamagnetic solutions behave very differently. In the latter case, the action of the diamagnetic molecules is so weak that the rotation is proportional to the concentration. With the former, however, the magnetic action is so strong that the reaction of the molecules upon each other is noticeable. For instance, with the perchloride of iron the rotation increases faster than the concentration when the latter becomes great enough. Becquerel verified again the experiment that with mixtures of iron filings and an inert powder the magnetic field increases more rapidly than the number of iron filings.

Becquerel now asked whether a gas should not have a measurable magnetic rotary power. All the earlier attempts to show this had been unsuccessful. Before making the apparatus adapted to show it

he needed an idea of the size of the effect which he might expect. The preceding law, $\frac{R}{n^2(n^2-1)} = 0.2$, approximately, used with gases of which the refractive indexes are known, shows that the amount of rotation should be very different from one end of the spectrum to the other and of the order of 0.0001 of that due to carbon bisulphide. So with an apparatus having a magnetic field 30 meters in length he expected a rotation of five to ten minutes of arc. Faraday had proved that the effect may be increased by repeated reflections of the light across the magnetic field. Becquerel employed this device in an apparatus about 3 meters in length to measure the rotary power of gases and their relatively great rotary dispersion.

Oxygen was found to be abnormal. Its rotary dispersion is extremely small and perhaps anomalous, the green giving less rotation than the red. This behavior may be compared with the well-known magnetic properties of oxygen. Carbon bisulphide furnishes strong evidence in support of the law, for in the liquid state the constant is 0.231; in the gaseous, 0.234.

Becquerel naturally searched for applications of his theory in the world about him. He looked for the action of the terrestrial magnetic field upon light, and with carbon bisulphide observed deviations of the plane of polarization of about half a degree. But a new question arose, Does the terrestrial magnetic field deviate the plane of atmospheric polarization, which, according to theory, must pass through the center of the sun? This study, requiring measurements of high precision, showed that the plane of polarization undergoes a daily oscillation about the theoretical plane, due for the most part to diffuse light, but there is a small residual variation caused by the earth's magnetism, 150 kilometers of air giving a rotation of about 20′ of arc.

This elaborate series of experiments would not have been complete had the practical side been neglected. At the congress of electricians in 1881 Becquerel proposed to measure electric currents in absolute units by means of the rotation of the plane of polarization by carbon bisulphide. He showed that this method is free from the perturbation at the ends of the magnet, the rotation formula being $R = K.4\pi NI$. By various experiments, made by the deposit of silver, the constant, K, was found equal to 0′.04841 at 0°. This gives a method of constructing a secondary scale for the ampere, precise though difficult in practice.

To return to the theories which had furnished motive for all these experiments, Becquerel combined his ideas in a theory of the magnetic rotary polarization and showed how analogous results could be

reproduced mechanically if a transparent body could be turned at a speed of millions of turns per second.

In this complete series of researches, conducted by Becquerel between his twenty-second and thirty-fifth years, we see the development of all the qualities of a true investigator—the directing theoretical ideas, the consummate experimental skill, the discussion of all the interesting results, those which concern the cosmical conditions of our existence together with their practical applications, and, finally, the theoretical coordination. This work, completed at 35, ranked Henri Becquerel as a master and gave cause for the glorious career which opened before him.

At the time of these recondite researches he was preparing others, all tending toward the study of the constitution of matter. They were to treat of the absorption of light and of phosphorescence. These led him to the discovery of the new rays.

Let us examine next his work on crystalline absorption. While examining the absorption spectra of various crystals he noted that the bands disappeared for certain orientations of the luminous vibration. Pushing further the study of this phenomenon, he saw that in all double-refracting crystals having absorption bands similar phenomena occur, and that the absorption in general is symmetrical about three principal axes; the more complicated the crystalline structure, the more complicated the law of absorption. There is, however, one general law binding them all. The bands observed through the same crystal have invariable positions in the spectrum; their intensity alone varies.

In uniaxial crystals the phenomenon is symmetrical about one axis. The absorption spectrum, in whatever direction observed, is formed by the superposition of two series of bands, one corresponding to the vibration normal to the axis, the other to those parallel to it. For every ordinary ray—that is, for every ray normal to the axis—the absorption spectrum is the same for the same length of path. For every extraordinary ray of which the vibration is orientated in the plane of the ray and the axis the absorption spectrum is as if the two components of the ray normal and parallel to the axis individually suffered absorption and then united upon emerging.

In biaxial crystals one law is common to both orthorhombic and clinorhombic crystals. Each band has three axes of rectangular symmetry. When the Fresnel vibration coincides with one of them, the absorption band is at a maximum; with another, it has a mean value; and with the third it is generally invisible. In orthorhombic crystals the three directions of absorption coincide with the directions of symmetry of the crystal. In clinorhombic crystals the phenomena are more complex and interesting. The axis of symmetry is always a

direction of principal absorption common to all the bands, but the other two principal rectangular directions of diverse bands of absorption may be variably orientated with the plane of symmetry, g_1. In certain crystals these directions depart very little from the principal axes of optical elasticity, in others they may make with these axes very great angles, reaching sometimes 45°. Becquerel gave to these directions the name, principal directions of anomalous absorption, and inferred from them important consequences.

These phenomena occur in crystals containing the rare earths and are probably due to the complexity of the bodies which form the crystals. De Senarmont had already shown that if we crystallize mixtures in variable proportions of the component substances, geometrically isormorphic but with the optic axes differently orientated with reference to geometrically like directions, we can obtain a crystal having any optical properties whatever, the resultant emergent vibration being due to the resultant of the partial vibrations traversing the various crystals, the symmetry of the total system depending upon the portions of each component. So in apparently like crystals the absorption may be wholly different, each component crystal absorbing certain radiations independent of its neighbors and there may be no relation between the axes of absorption corresponding to these bands and the directions of symmetry of the crystal. If certain crystals have principal directions of anomalous absorption, it is because they are such mixtures of crystals. Crystals containing didymium show the necessity of admitting its division into neodidymium and præsodidymium. Demarcay was able to separate the distinct elements in præsodidymium, the existence of which Becquerel had thus shown the necessity. In neodidymium there are bands which characterize complex crystals.

This method of analysis can indicate bodies existing in a crystal which are destroyed by its solution. If, having noted all the absorption bands in a crystal of sulphate of didymium, we dissolve it, the spectrum of the solution is notably different, certain bands have disappeared, others have suffered displacement, while yet others have remained unchanged. The bands modified are those which in the crystal were marked by these anomalies and the variations may be explained if we admit that there exists in the crystal such a mixture which is completely destroyed and transformed by the water.

The separation of the rare earths is very difficult. They are very numerous and distinguished from each other only by extremely small variations in their physical and chemical properties. It is generally almost impossible to purify them. It would be very valuable to be able to seize, by some optical process, in the heart itself of a mixture, a crystalline body which shows this anomalous absorption and which, the moment the body is dissolved, disappears to take place as

another compound. It would be a true method of spectrum analysis which could be employed in researches relative to the rare earths.

After having shown upon many crystals the fruitfulness of his method, Becquerel closed his research in this line by, as usual, reuniting into a theory the facts observed. The intensity of a ray after having traversed a unit thickness of a crystal must be $i=(a\cos.^2\alpha+b\cos.^2\beta+c\cos.^2\gamma)^2$ for a given wave length, the ray making the angles α, β, and γ, with the principal absorption axes, the intensity observed along the three axes being a, b, and c. But there are cases where two absorption bands are superposed in the same part of the spectrum having different principal directions of absorption. Then the photometer measures must be represented by the product of two expressions of the same form. Thus we may have an asymmetric curve for the intensity as a function of the angles α, β, γ. This takes place in epidote, and Becquerel was able to explain the apparently paradoxical results of Ramsay in making photometric measures for various orientations in the plane, g_1, of epidote.

We see in this series of researches the same qualities of mind present in the earlier one; extremely delicate experiments directed by theoretical ideas and the final embodiment in a theory rendering numerical account of the observed facts. The problem brought to this point had no further interest for Becquerel; he left to others the patient work of applying his methods. He himself started on a new path, one already laid out for him, which, in a sense, was an heritage. Edmond Becquerel had already made discoveries upon it of the first order. In phosphorescence Henri Becquerel found a subject well adapted to his trend of mind and where his radical ideas could bear full fruit. We find again the double line of work, the theoretical and the practical, side by side. He showed the first in establishing a new method for the spectroscopic analysis of flames, the other in discovering two distinct laws: First, the law connecting the radiation engendering phosphorescence and that emitted from the phosphorescing body; second, the law connecting the diminution of the emitted energy with the time. This series of experiments is also of the first rank, for the study of the constitution of matter for phosphorescence is certainly intimately connected with molecular resonance. Phosphorescence results from selective absorption, but the nature of the radiation is such that a purely temperature connection between the phosphorescent emission and the nature of the body's absorption is an insufficient explanation of the emission, which is itself selective. These phenomena seem related to those of the selective emission of incandescent vapors, and so it was natural to look for laws analogous to those governing the luminous emission of gases and vapors. It is true that the molecules are less free in solid

phosphorescing bodies than in gases, and the light emitted less simple; yet Becquerel was able to unravel definite relations.

Edmond Becquerel had already shown that if the infra-red rays strike an excited phosphorescing body the phosphorescence is destroyed, just as it would have been had the temperature of the body been raised. The extinction is preceded by a temporary increase of the phosphorescence, as if the stored-up energy was given out at a greater intensity during a shorter time. Generally the two phases occur so rapidly that the final extinction alone is appreciable. Edmond Becquerel had thus commenced the study of the infra-red of the spectrum. Henri Becquerel resumed this study, making many important advances. He studied the solar spectrum by means of phosphorescence and described in this infra-red portion unknown or little known bands between the wave lengths, 0.76μ and 1.9μ. Abney, by direct photography, had gone as far as 0.98μ. Langley with the bolometer had explored a much greater region and had recognized the more interesting of these bands of Becquerel. But in the region, relatively small to be sure, where the phosphorescent method is applicable, it could then detect finer lines than the bolometer. Becquerel studied new absorption and emission spectra: he showed that the liquid-water absorption nearly coincides with that of atmospheric water vapor; that the compounds of didymium and samarium have characteristic lines in the infra-red which may serve as standard marks; finally, he mapped the characteristic lines in the infra-red of the incandescent vapors of potassium, aluminum, zinc, cadmium, lead, bismuth, silver, and tin.

While some substances lose their phosphorescence nearly uniformly over the infra-red, with others the extinction is unequally rapid in different regions. The extinction is produced under the influence of definite radiations, often to the exclusion of the neighboring regions, so that the spectrum consists of one or more bands where the extinction has been active, separated by regions where it has been either much smaller or nil. Under the influence of the infra-red radiations the phosphorescence varies in color with the time. This may be noted in the phosphoroscope. So even in the various infra-red bands in the same substance it was found that the color can not always be the same.

It is interesting to correlate these facts with the very similar behavior in the violet and ultra-violet. The ensemble of the bands of excitation, of emission, and of extinction must be connected by analogous formulæ with the various radiations emitted by incandescent vapors, for both are intimately connected with the vibration periods of the molecules.

The most remarkable phenomena are shown by the compounds of uranium, and it was the study of these which led to Becquerel's dis-

covery of radio-activity. Uranium forms two distinct series of salts. Edmond Becquerel had shown the phosphorescence of one set, the second does not phosphoresce. Henri Bacquerel soon noted that the latter salts have characteristic bands of absorption in the visible and the infra-red spectrum. Studying further the compounds of the first class, he noted that most of them phosphoresce as had already been shown and that they have in general a discontinuous spectrum of seven or eight bands or groups of bands between the C and the F lines; these bands vary according to the nature of the compound. The compounds have selective absorption bands which correspond to all the radiations which will excite the phosphorescence. If the body is excited by the light of the wave length of any one of these latter bands it will give out its total emission spectrum of all the wave lengths proper to its phosphorescence. Becquerel formulated this law: The difference in the oscillation frequencies in passing from one band to another is a constant, the bands of absorption continuing the series formed by those of emission. The latter seem to be the subharmonics of the former. Often one or two of the less refrangible absorption bands coincide with the more refrangible ones of emission. It seems probable that the absorption forms some kind of synchronism with the periods of the emission, but it is not expected that they will be found to be subharmonics. They are essentially distinguished from incandescent vapors in absorption. The ordinary theories of resonance are incapable of explaining them, but the simplicity of the law which binds them gives hope some day of the possibility of a mechanical explanation.

It is remarkable that the second series of uranium salts which do not phosphoresce but seem to degrade into heat the selectively absorbed radiation, should have bands which follow with a notable regularity the same law which holds for the emission bands of the other series. The bands have not, however, the same relative intensities.

We have just seen the theoretical difficulties offered by these phenomena. Edmond Becquerel had already studied and formulated the variation of the intensity of the phosphorescent emission with the time. His formula, however, held only for very short periods of time. Nor was the one derived by Wiedemann sufficient. The formula, $i = i_0 e^{-at}$, was deduced theoretically from the hypothesis that the molecular degradation of energy is proportional to the velocity of what we will now call electrons. Becquerel thought it better to make this degradation proportional to the square of the velocity and so obtained the formula $i = i_0 \left\{ \frac{1}{a+bt} \right\}^2$. As the photometric measures of the total phosphorescence intensity did not agree with this, Becquerel, remembering the changes of color, thought it possible that a similar

term ought to be used for each band, so that if there are two bands in the spectrum the formula becomes $i = i_0\left\{\left(\frac{1}{a+bt}\right)^2 + \left(\frac{1}{c+\alpha t}\right)^2\right\}$. He verified this formula in several cases, so that it seems proved that the phosphorescent phenomena follow a law probably adaptable to some mechanical explanation but much more complicated than acoustical resonance or other analogue to which we are at present accustomed.

From that moment, for Becquerel, phosphorescence became a source offering mysterious properties, the unraveling of the secret of which would embrace a multitude of new discoveries.

RADIO-ACTIVITY.

When the discovery of Röntgen was announced, Becquerel, like many others, at once tried to see whether phosphorescent bodies emitted photographic or phosphorogenic radiations which would traverse opaque bodies. And here we may still better appreciate the subtlety of Becquerel's mind. In the midst of a maze of seemingly contradictory facts, he knew, by his marvelous intuition, how to avoid the paths to error and to take that which would lead him by infinitely small manifestations to the fundamental phenomena of radio-activity, that immortal discovery which has already revolutionized modern physics and promises to lead the physics of the future into fields as yet unrealized.

The biography now becomes difficult. It could be made nothing more than the renumeration of Becquerel's astonishing discoveries without explaining the extraordinary conditions under which they were produced. Those physicists who may read this will recall that fever of excitement among men of science which followed in 1896 the announcement of Röntgen's discovery. They will recall, too, the first experiments of Becquerel, which raised the doubts of the older school and the curiosity of the younger. Then Becquerel, aroused by the daily disclosure of new truths and by the increased publication of his works, accumulated in three years a mass of results that confounds us. And we should also note at this time the devoted collaboration of his assistant, M. Matout, in whom he inspired admiration as a man of science and an unlimited personal attachment.

Ordinary phosphorescent substances give off no emanation capable of traversing black paper. But it is not so with the compounds of uranium, whose peculiar properties Becquerel had already recorded. By first covering a photographic plate with black paper and placing over the latter a salt of uranium excited by direct sunlight, he succeeded in obtaining an impression upon the plate. But one day the sunlight disappeared a moment after the exposure had been started

and the apparatus was left in the dark. Later the plate was developed and the impression was found as strong as if the sunlight had struck the salt. Upon trying the experiment again without sunlight the same result was reached as if the sun had been used. Although this uranium compound, which had been prepared some time, was now kept in the darkness in a lead box, yet it still continued to give the same results.

The discharge of an electrified body under the influence of the uranium emanation was next tried. This was at that time the only process known which would give quantitative measures of this strange power. Then it was necessary to see if the phosphorescent state was necessary for the newly found emanation. A nitrate of uranium crystal, whether in solution or melted in its water of crystallization, gave the same effect as when in the solid state, although in neither of the liquid states would it phosphoresce. An attempt to see whether bodies near such active compounds became active by a phenomenon analogous to phosphorescence was unsuccessful. It was several years later that the power of radium enabled M. and Mme. Curie to show this and the profound difference between this new phenomenon and luminous phosphorescence.

Some odd results, not yet understood, led Becquerel for a moment to erroneously believe that the new rays were ordinary radiation. But he soon saw his error, noting that the propagation of this new emanation took place as well across pulverized matter as across solid, continuous bodies.

Since all the compounds of uranium, whatever their chemical or physical state, showed these phenomena, it was therefore natural to attribute them to the uranium itself. Pure uranium was tried and gave more intense results than the salts. It was now made evident that neighboring bodies became the source of a secondary emanation as long as they were struck by the uranium discharge, but that the phenomenon ceased as soon as the body was removed from the presence of the uranium.

By pushing the experiments with the electrical discharge still further it was shown that the air is rendered conductive and remains so a few moments and that this plays an essential rôle in the phenomenon. Air, active under the influence of the uranium and blown upon an electroscope actively discharges the latter. If ordinary, inactive air is blown between the uranium and the ball of the electroscope, the latter is discharged more slowly. The emission seems independent of the temperature of the uranium. The temperature of the gas, however, modifies the discharge.

In order to regulate this method of measuring the emanation, it was necessary to find some law governing the discharge under the varying potential. Becquerel established a limit of the velocity of

discharge for potentials above 300 volts; Rutherford later called this the "saturation current."

Finally, by studying the modification of the velocity of discharge produced by the interposition of lamina of different substances, Becquerel showed the complexity of the emanation emitted by the uranium. From now on these radiations were called "Becquerel rays."

All these results were verified by Rutherford, who extended them, characterizing by their absorption two classes of rays: The α rays, very active and greatly absorbed by the air; the β rays, less active and much less absorbed. He applied to gases, rendered conductive by these rays, the theory of ionization, which J. J. Thomson was then developing, and showed the identity of the phenomena produced in the air by the Becquerel rays and the Röntgen rays.

While Becquerel's results were being verified in England, M. and Mme. Curie in France and Schmidt in Germany were searching for this emanation from other bodies. Mme. Curie and Schmidt discovered it simultaneously in thorium. Mme. Curie found that all active bodies contained either uranium or thorium. She determined by the quartz-piezo-electrical method of Curie that each compound of uranium, whatever its history, possessed the same power of discharging—the same radio-activity—using the name adopted by Curie. The two Curies then tried to isolate the body endowed with the property of radio-activity; and by an immense amount of work, using Becquerel's rays and Curie's piezo-electrical method in their analyses, they finally discovered polonium and then radium. Using pure uranium as the unit of radio-activity, radium chloride has an activity of 1,800,000.

Becquerel could now continue his researches with the extremely active products placed at his disposal by the Curies. His earlier experiments he repeated with polonium and radium, and showed, by his absorption tests, that polonium emits an emanation different from that of radium. Utilizing the admirable collection of phosphorescent compounds left by his father, Becquerel did not delay in establishing several new properties of the emanation from the new products, showing that each of them emitted a complex bundle of rays exciting in a special manner the diverse phosphorescent substances. By his absorption method he showed that the very penetrating rays excite the double sulphate of uranium and polonium and that the most penetrating rays excite the diamond. Finally, he noted that the radium emanation can give back to bodies the property which they may have lost of becoming phosphorescent by being heated. This may also be accomplished by means of the electric discharge.

Becquerel noted that the radium emanation gives to chlorine a phosphorescence much more persistent than that produced by ordinary light, and compared this with the similar result produced by

the cathode rays as shown by Sir W. Crookes and Edmond Becquerel. He compared the chemical phenomena produced by the cathode rays and those which the Curies had observed with the action of radium upon glass.

It was but a step to Becquerel's examination of the effect of the magnetic field upon the emanation. Giesel, Meyer, and Schweidler had already obtained some results along that line, but they were unknown to Becquerel. Becquerel's observations, when completed, were more profound, more fertile than those of his predecessors. He observed the important fact that the radiation, deviated like the cathode rays by the magnetic field, suffers a dispersion. This showed that the emanation is composed of electrons having different velocities. At the same time, working with an electrometric method, the Curies showed that in the emanation from radium there is an undeviated part much more absorbed than the other rays, thus giving a new distinction between the α and β rays of Rutherford. Polonium according to Becquerel gives only the nondeviable rays. But at the same time Villard showed that in the nondeviable bundle there exists, besides the very absorbable α rays, a set, extremely transmissible, which he called the "γ rays," and which are identical with the Röntgen or X rays.

The remarkable studies of J. J. Thomson on the cathode rays recorded that from the trajectories of the electrons in a known magnetic field we may determine the quantity $\frac{mv}{e}$, where m is the mass of the electron charged with a quantity of electricity e, and having the velocity v. The trajectory of the rays discharged normal to the field should be a circle whose radius $R = \frac{mv}{He}$, where H is the intensity of the field. It was necessary to see if the radium rays gave trajectories whose radius equaled $\frac{mv}{e}$, analogous to cathode rays. Experiments showed this to be true and that all the preparations of radium or its salts gave the same kinds of rays. It served also to show that the dispersion in the magnetic field could serve for the study of the penetrability of the various emanations, for the more deviable the more penetrating are the rays. The images obtained by placing various screens separating a photographic plate from a morsel of radium in the bottom of a lead trough, and all placed in a magnetic field, allowed, by means of the images upon the plate, a determination of the limits to which the emanations penetrated the screens. Moreover, the radii of curvature were easily calculated. Knowing the field H, the products RH could be easily deduced. These products, equal to $\frac{mv}{e}$, lay between 637 for copper and 3082 for lead. Admitting velocities analogous to those of the cathode rays, the values, $\frac{m}{e}$, could be ap-

proximately found, showing whether the emanation should have a sensible electric deviation. Becquerel made the calculations and prepared the experiment at the same time that the Curies demonstrated directly that the deviable rays of radium carried negative charges. On March 26, 1900, at the Académie des Sciences, he published the confirming results. Dorn independently published the same results, depending on the calculations of Becquerel.

Knowing the radius of curvature for a cathode ray in a known magnetic field and its electrostatic deviation, we may calculate $\frac{e}{m}$ and v. When his discovery was well assured Becquerel published figures obtained from the absorption in black paper, giving $v=2.37\times10^{10}$ and $\frac{e}{m}=1.32\times10^{7}$, very close to the last given by Kauffmann.

While Becquerel struggled against his insufficient means for constructing the necessary in vacuo apparatus, Kauffmann completed experiments with sufficient accuracy to conclude that $\frac{e}{m}$ varies with the velocity—that is to say, that mass, the constant which has seemed so well established since the time of Newton, has no absolute existence and that we can consider its coefficient as constant only with velocities infinitely small compared with the velocity of light. We will say nothing further on this aspect of radio-activity. It now passes out of Becquerel's domain. Indeed before the flood of foreign investigations which furthered his results and before the new results secured every day, he had to leave to others the experiments for which he had neither the material nor the means.

After the α and the β rays had been clearly distinguished by the experiments already stated, it was questioned whether the former are only slightly deviable or not deviable at all. Rutherford performed an experiment from which he concluded that they are slightly deviable but his conclusion was too involved to carry conviction. Becquerel took up the question, using accurate measures made upon his photographic plates, and was able to establish a weak deviation undoubtedly, the α rays forming a pencil clearly defined and not showing any sensible magnetic dispersion. These rays are analogous to the canal rays of Goldstein. The curvature of the α rays seemed to augment with the length of path in the air. Although the great absorption of the rays by the air made difficult the simultaneous study of the magnetic and electric deviation, the problem was solved by Des Coudres. The experiments of Becquerel and of Rutherford proved that the change of curvature in traversing a thin sheet of aluminum is due to a noticeable retardation of the charged corpuscles.

To Becquerel it seemed due to an augmentation of the mass, to Rutherford to a diminution of the velocity.

Becquerel found that polonium gives rays that are identical with the α rays of radium. An exhaustive study of uranium, even in vacuo, disclosed no α rays, but it was found to emit very deviable β rays—that is, rays of small velocity.

The beginning of these studies had shown the existence of secondary rays produced by the bombardment of another body by the Becquerel rays. Further study showed that all radium rays do not possess this property. The most rapid corpuscles traverse aluminum and suffer no modification. Those for which $RH=3.436$ are the first to suffer change and produce the secondary rays after passing through the aluminum. When $RH<1.500$ they are completely absorbed by the aluminum and give no emission. The secondary rays are deviated like the primary in an electric field.

It was these secondary rays which produced the intense impression on the photographic plates of Becquerel. The very penetrating emanation traversed the lead, producing the secondary rays which then affected the plate. These rays produce the augmentation of the impression along the screen hit by the Becquerel rays. These experiments remade with polonium showed that in time the secondary rays due to mica indicate a much more penetrating emanation than that ordinarily noted from polonium.

Becquerel studied the transformation of white into red phosphorus under the influence of these emanations and showed that the slightly penetrating rays produced the essential part of the action. The α rays could not be tried because of the necessity of protecting the radium.

The fertile success of the ionization theory made it interesting to see whether analogous phenomena took place in solid dielectrics. J. J. Thomson showed that it occurred with the X rays. Becquerel showed that liquid or solid paraffin became conducting under the action of the rays. That the action continued constant in the same apparatus during a year indicated that it took place even when the paraffin had reached its permanent state.

At the time of these discoveries the Curies were bringing to notice induced radio-activity, and Rutherford, the emanation of radium with its curious properties, the exhaustion of the solution which gave the emanation, and the recovery of the radio-activity after a certain time. Thorium had an emanation of its own. None could be isolated from uranium, and yet Becquerel showed that certain phenomena appeared to indicate one. Sir W. Crookes showed that by fractional crystallization of the nitrate of uranium in ether the foreign matter became reactive, the nitrate less and less so. He attributed this to a new body which he called uranium-X. Becquerel showed that these

phenomena follow the same laws as those of the salts of radium in solution and that the nitrate crystallizes reactive after a time. It seemed then that uranium has an emanation. He showed that the double sulphate of uranium and potassium is spontaneosuly luminous in the dark like the radium salts, only the effect is far smaller than was expected. Becquerel proved that the phenomenon of Crooke's spinthariscope is due to the cleavage of the hexagonal blende under the bombardment of the α rays.

Becquerel considered with Curie that the radio-active phenomena are due to a constant evolution of the atom, the atoms of the active bodies being variable and constantly destroyed by explosions. The débris may be in part of inert matter, partly of groups of electrons or single electrons which constitute the various emanations, the α and the β rays, and communicating to the ether concussions (γ rays). The corpuscles remain scattered in matter or in space. According to this theory the emanation may be regarded as a group of electrons carried by gases or matter. Perhaps, as Filippo Re believes, we may consider the radio-active atom as a condensing solar system; perhaps with Perrin, as a solar system from which the exterior planets are escaping. Becquerel said of these hypotheses: "Re's may be considered of equal worth with the inverse hypothesis; they both deserve the interest due attempts to connect by common laws the infinitely small atom with the infinitely great universe.

DIVERSE RESEARCHES.

Along with these great problems, in which Becquerel held such a leading position, he worked on certain other problems which the greater ones had temporarily replaced: His research with Edmond Becquerel on the temperature of the sun; then in 1879, on the magnetic properties of nickel and cobalt; then he showed by interference methods that in the propagation of radiations across rotary-polarizing magnetic fields the right and the left circularly polarized components travel with different velocities. Later, when the Zeeman effect was discovered, he took up his latest ideas relative to the action of the magnetic field upon light and showed the connection between the Faraday and the Zeeman phenomena. Then, in collaboration with Deslandres, he studied these phenomena experimentally, particularly with iron. They showed that, in this case, certain rays are unaffected, some give triplets, other quadruplets. The ray, 0.3865 μ, is anomalous; the two extreme rays are perpendicularly polarized to the lines of force, the other two parallel.

Becquerel also showed in a beautiful way the anomalous dispersion of sodium vapor by the classic method of crossed-prisms spectroscopes, but with a very original disposition of the apparatus. He

produced a prism of sodium vapor by means of a small platinum trough held over a yellow sodium Bunsen flame. He received the spectrum of white light formed by this upon the slit of his grating spectroscope and the hyperbolic form of the D lines indicated the phenomenon of the anomalous dispersion.

We will close this short notice of Becquerel with recalling that both he and M. Curie were the first to suffer the painful effects of radium upon the human body. Becquerel, by carrying in his armpit for several hours a preparation of radium, contracted an ulceration in his side which was very long in healing, and at another time he received a noticeable pigmentation. With Curie he published his observations at about the same time that Curie had suffered the effects upon himself. These two great men were thus victims of the discovery which led them both to glory, and perhaps the weakness caused by their injuries was partly to blame for their premature ends.

CONCLUSION.

And now that I have so hastily reviewed these great accomplishments, may I be permitted, as a friend of Becquerel and of France, to express a heart-felt regret. Since Henri Becquerel built his work with the poorest of scant material, the regret which I wish to express is that so great a man had not at his hand the credit, the equipment, and assistants found in so many foreign laboratories, which would have more often allowed Becquerel to arrive ahead of others at the goal of the fertile paths which he disclosed.

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